APPENDIX C

Vibration and Sound Level Assessment

VIBRA-TECH
The Vibration Monitoring Experts

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March 27, 1995

Mr. Bill Johnson
Department Of Transportation
State Of Georgia
3993 Aviation Circle
Atlanta, Georgia 30336

RE: Addendum To Study Of January 16,1995
Sound And Vibration Impact Assessment
Decatur Belt Upgrade, Atlanta, Georgia

Dear Mr. Johnson:

As requested, Vibra-Tech Engineers has prepared the following as a clarification of the findings reported in the above referenced Sound And Vibration Assessment.

The findings presented in this report are based on calculations derived from The United States Department Of Transportations Federal Transit Administration's Guidance Manual for Transit Noise And Vibration Impact Assessment. This manual is marked as a draft and is dated March 1995. Specifications pertaining to the anticipated types, speeds, and number of trains per day time hour were provided by the Georgia Department of Transportation.

Based on available information, it has been assumed that a worst case hourly day time volume of rail traffic will occur between the hours of seven (7:00) and eight (8:00) AM. This volume will consist of one (1) Amtrack train composed of two (2) engines and eight (8) cars and one (1) commuter train composed of one (1) engine and three (3) cars. The maximum anticipated speed for either train in the Ansley Park / Piedmont Heights area will be forty-five (45) miles per hour. Applying the guide lines and formulas found in section 6.2.1 of the Guidance Manual for Transit Noise and Vibration Impact Assessment, an hourly fifty foot project Leq of 62 db would be expected from the proposed combination of Amtrack and commuter rail traffic on this line.

Actual day time Leq readings collected from eight (8) representative locations in the Ansley Park / Piedmont Heights study area ranged from fifty-five (55) to seventy-one (71) db. The distances from these recording locations ranged from one-hundred ten (110) to five-hundred eighty (580) feet from the Decatur Belt Rail Line.

The following chart contains recording locations, measured Leq readings, distances, and calculated exposure levels for each structure. Exposure levels are based on our recalculation of the Exposure vs. Distance Curve For Fixed Guidway, figure 6-6, of the Guidance Manual for Transit Noise and Vibration Impact Assessment. A similar Exposure vs. Distance curve representing this recalculation is included at the end of this report in figure 1-A.

Location	Distance	Measured Leq	Exposure Level
1-A 403 Montgomery Fy.	150 ft.	60 db.	54 db.
1-B 189 Avery Drive	450 ft.	55 db.	48 db.
1-C 201 Avery Drive	220 ft.	56 db.	52 db.
1-B 1758 Flagler Ave.	175 ft.	60 db.	53 db.
1-E 1510 Piedmont Ave.	110 ft.	61 db.	56 db.
1-F 80 Golf Circle	210 ft.	64 db.	51 db.
1-G 127 Avery Drive	540 ft.	55 db.	46 db.
1-H 1800 Flagler Drive	180 ft.	71 db.	53 db.

Based on the above chart, it appears that the projected exposure levels for all eight (8) representative structures surveyed during this study would fall well below existing day time Leq levels. The final results of our calculations have been plotted on an Existing Noise Exposure graph similar to that found in chapter three of the Federal Transit Guide lines titled figure 3-1. This plot may be found at the end of this report in figure1B.

If you have any questions concerning this material or should you require farther clarification of the findings of our Decatur Belt Upgrade study of January 16, 1995, please feel free to contact us.

Sincerely,
Vibra-Tech Engineers

Randy W. Denman

Randy W. Denman
Operations Manager

EXPOSURE - VS - DISTANCE CURVE FOR FIXED GUIDWAY
DECATUR BELT RAIL LINE ATLANTA, GEORGIA
ANSLEY PARK / PIEDMONT HEIGHTS STUDY AREA

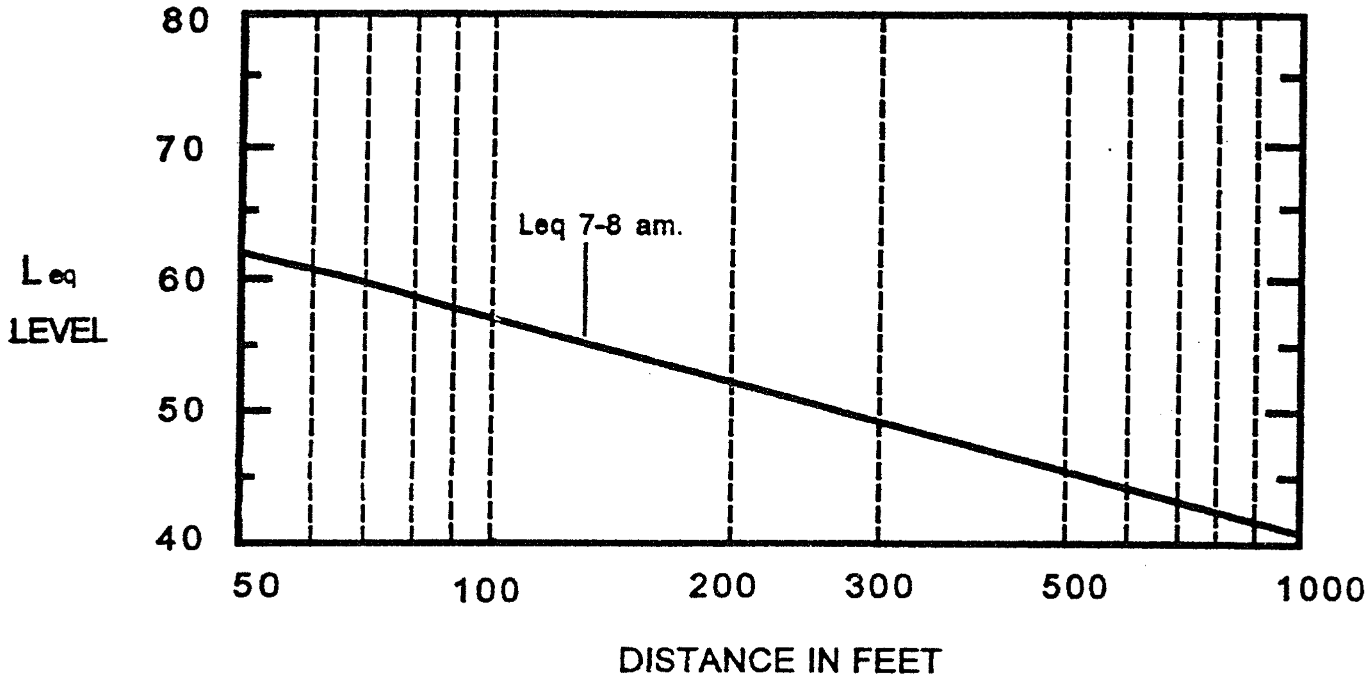

figure 1-A

NOISE EXPOSURE CONSIDERATIONS
DECATUR BELT RAIL LINE ATLANTA GEORGIA
ANSLEY PARK / PIEDMONT HEIGHTS STUDY AREA

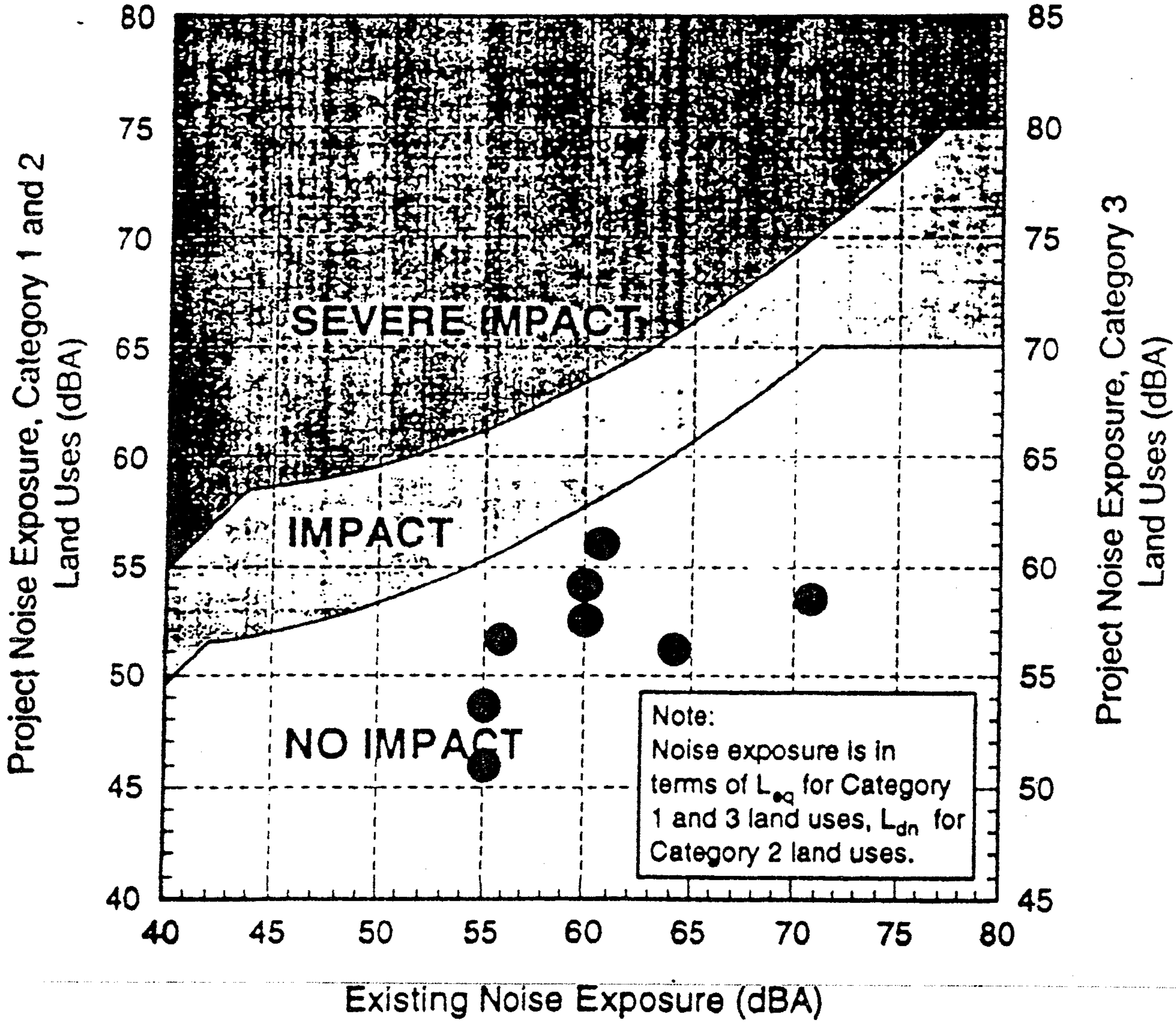

figure 1-B

VIBRA-TECH
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404-972-8775 FAX 404-985-5583

January 16, 1995

Mr. Bill Johnson
Department Of Transportation
State Of Georgia
3993 Aviation Circle
Atlanta, Georgia 30336

RE: Sound And Vibration Impact Assessment
Decatur Belt Upgrade, Atlanta, Georgia

Dear Mr. Johnson:

As requested, Vibra-Tech Engineers has prepared the following assessment concerning the possible impact on near by residential structures from the proposed future addition of light commuter and Amtrack traffic to the existing Decatur Belt rail line, Atlanta, Georgia.

The format for data collection during this assessment, as outlined in Vibra-Tech's initial proposal of October 19, 1994, involved five (5) distinct data collection tasks. The presentation and discussion of the findings from each of the five tasks along with a description of the instrumentation and techniques employed for each comprises the body of this report.

The findings of task number five (5) dealing with the statistical prediction of rail induced vibration levels and associated effects on a typical, representative structure located in the Ansley Park/Piedmont Heights study area have been reported under separate cover. Collection of data and reporting of this section of the study is being conducted by personnel in Vibra-Tech's Louisville, Kentucky structural engineering facility.

Please feel free to contact us if you have any questions concerning this assessment or require further interpretation of data collected during this project.

Sound And Vibration Impact Assessment
Decatur Belt Upgrade, Atlanta, Georgia

PROCEDURE

The general approach to this assessment was to measure and compare typical rail induced air and ground borne vibrations collected from representative locations along the Decatur Belt rail line with those generated by Amtrack, heavy freight and commuter rail traffic in presently impacted areas.

Vibra-Tech's preliminary assessment of the Decatur Belt in June, 1994 suggested that the Ansley Park / Piedmont Heights area would be the most representative study area and possibly the most vibration sensitive section of this rail line. For this reason, the study area for this assessment has been defined by structures falling within a distance of two-hundred and fifty (250) feet to either side of the Decatur Belt rail line between Interstate I-85 and the Piedmont Road crossing.

The collection of off site data in the presence of Amtrack and heavy freight traffic occurred primarily along Southern Rail Roads line running between the Armour Rail Yard and the Brookwood Amtrack station located at the intersection of Peachtree Street and Dearing Road. This section of track was chosen such that data could be collected from Amtrack as well as heavy freight trains moving at the anticipated maximum Decatur Belt speed of thirty-five (35) to forty (40) miles per hour. Due to the relatively close proximity of this area to the Ansley Park /Piedmont Heights study area, it was assumed that the general geology of the two areas would be similar and vibration transmission characteristics would be relatively consistent. Seismic attenuation tests as conducted in Task 4 tend to verify this assumption.

Vibrations from typical single engine commuter trains were collected by Vibra-Tech representatives located in the Chicago and Philadelphia areas. As with Amtrack and heavy freight trains recording locations were chosen to provide data in the thirty-five (35) to forty (40) mile per hour range. The commuter trains tested during this study were composed of from three (3) to five (5) cars. Data was collected under fully as well as partially loaded conditions at distances of from ten (10) to two-hundred (200) feet.

Typical rail operations along the Decatur Belt were found to take place on week days between approximately eleven o'clock (11:00) AM. and four o'clock. (4:00) PM. Rail traffic appeared to occur on a random as needed schedule with an average of three (3) to four (4) trains entering the study area per week. It was found that all trains using this track were servicing local customers and none were considered through trains. The estimated travel speed of trains observed in this study was between ten (10) and fifteen (15) miles per hour. Trains and single engines (including two (2) Amtrack engines) were also observed sitting for extended periods of time with engines idling at various points in the study area. Typically, trains were composed of from one (1) to twelve (12) cars and were generally pulled by one (1) engine.

INSTRUMENTATION

All measurements of ground borne vibrations were conducted with Vibra-Tech's Everlert Ve seismic recorders. Ground vibrations were recorded in inches per second, peak particle velocity in a frequency range of from two (2) to two-hundred and fifty (250) cycles per second. Direct displacement, acceleration, and Fourier analysis are also standard calculations that have been conducted on selected representative segments of data collected with these instruments. The instruments were coupled to three (3) component triaxial sensor clusters resolving vibrations into transverse, vertical and longitudinal directions.

The Everlert Ve seismic recorder is a seismically activated digital recorder capable of recording particle velocities in the range of 0.001 inches per second up to 10.0 inches per second. During all phases of this study the instruments were programed to trigger and record all vibrations exceeding a level of 0.005 ips. The sampling period following each exceedance of the trigger level was set for a duration of ten (10) seconds. The three (3) channels of ground data are temporally stored on the instruments internal hard drive and later transferred to floppy disk for analysis and permanent storage.

Existing ambient sound level measurements reported in this assessment were collected with a General Radio model 1945 Community Sound Level Analyzer. The model 1945 Analyzer is a portable sound level recorder capable of measuring and recording "A" weighted sound levels in the range of from forty (40) to one-hundred and twenty (120) decibels dbA. This instrument is also capable of calculating exceedance values for sound level data recorded during each of three (3) user selectable recording periods. Each of the three periods may be programed to collect data from time segments of from one half (1/2) up to twenty-four (24) hours in length.

Direct measurements of sound levels produced by all rail traffic reported in this assessment were conducted with a General Radio model 1933 octave band analyzer covering standard octave bands as specified in ANSI STD. S1.11 IEC 225. The model 1933 analyzer is a portable sound level meter capable of measuring "A" weighted sound levels in the range of from twenty (20) to one-hundred and twenty (120) decibels dbA and can perform standard octave band measurements as specified.

DISCUSSION OF RESULTS: TASK 1

During this phase of data collection Vibra-Tech recorded sound and vibration levels from typical Amtrack, light commuter, and heavy freight trains at the off site locations discussed previously in this presentation. The purpose of this effort was to determine typical levels of sound and ground vibration for trains moving at the anticipated future maximum Decatur Belt travel speed of thirty-five (35) to forty (40) miles per hour. Vibrations were recorded at various points on the ground as well as on the floors, walls and attics of selected residential homes near the off site sections of test track.

Seismic data collection was accomplished by placing a series of Everlert Ve seismic recorders on the ground extending away from each section of test track at intervals of twenty (20) feet. The nearest instrument was consistently placed approximately ten (10) feet from the track and generally lay at the point of contact between the ground and stone ballast beside the tracks. In all cases, eleven (11) instruments were used to achieve a distance of two-hundred (200) feet with an additional instrument placed at two-hundred and fifty (250) feet to confirm attenuation of vibrations below the instruments operable lower end resolution of 0.001 inches per second. In order to collect data beyond approximately the one-hundred (100) foot interval, instruments were triggered manually as trains passed due to vibration levels falling consistently below the instruments lowest self triggering setting of 0.005 inches per second.

Figure number one (fig.1) found on the following page of this report graphically represents the findings of this portion of the study. A comparison is also made between these and existing rail induced vibration levels found in the Decatur Belt study area resulting from a duplicate test situation.

In general it was found that for distances closer than approximately one-hundred (100) feet all forms of thirty-five (35) to forty (40) mile per hour rail traffic exceeded the vibration levels generated by the present slower moving Decatur Belt rail traffic. At distances of one-hundred (100) to two-hundred (200) feet, light commuter rail traffic produced vibrations equal to or lower than the existing Decatur Belt traffic. Amtrack and heavy freight traffic were observed to produce levels slightly above present Decatur Belt levels.

At approximately one-hundred and sixty (160) feet and beyond the present Decatur Belt traffic along with the higher speed Amtrack and light commuter trains recorded off site all produced ground vibrations at or below the typical levels of human perception, 0.02 to 0.03 inches per second depending on the predominant frequencies of the wave forms. In general, wave forms with predominant frequencies below twenty-five (25) cycles per second appear to be more noticeable to occupants of residential structures at levels near the limits of human perception than do higher frequency vibrations.

Wave forms possessing predominant frequency content at or below twenty-five (25) cycles per second are also more likely to coincide with the natural resonant frequencies of residential structures. Such matching of frequencies may result in the amplification of in coming ground or air vibrations as they pass through a structure making these vibrations some what more noticeable to occupants. Vibra-Tech's experience indicates that interior walls and ceilings tend to respond at frequencies of eighteen (18) to twenty-five (25) cycles per second. Such response is typically evidenced by buzzing or rattling of loose hanging objects such as pictures or wall lamps. several of the test structures monitored during this study exhibited such interior wall responses to 35 to 40 mile per hour Amtrack and heavy freight traffic. However, no structural response was noted from light commuter or present Decatur Belt traffic.

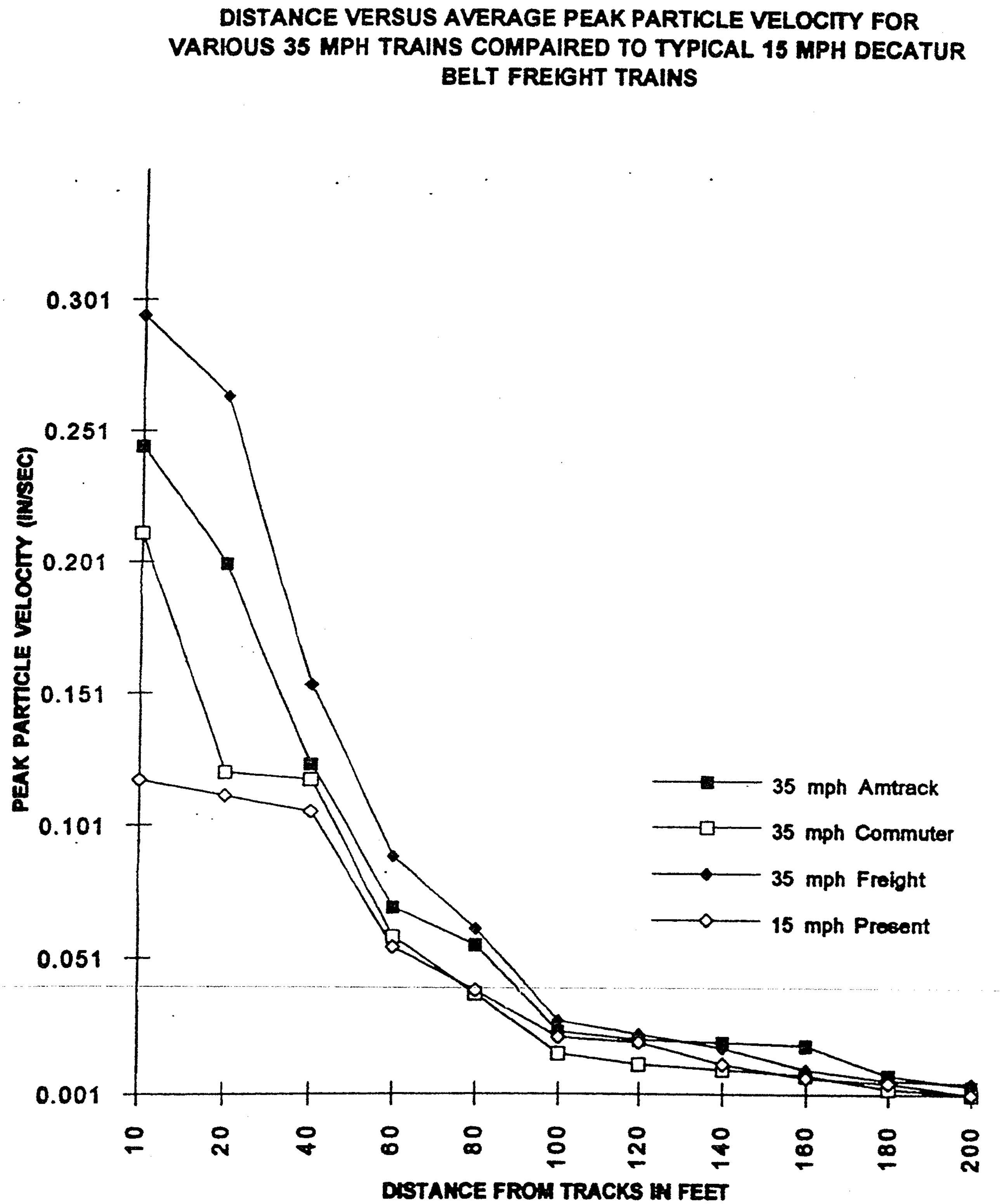

DISTANCE VERSUS AVERAGE PEAK PARTICLE VELOCITY FOR VARIOUS 35 MPH TRAINS COMPAIRED TO TYPICAL 15 MPH DECATUR BELT FREIGHT TRAINS
PEAK PARTICLE VELOCITY (IN/SEC)
0.301
0.251
0.201
0.151
0.101
0.051
0.001
35 mph Amtrack
35 mph Commuter
35 mph Freight
15 mph Present
10
20
40
60
80
100
120
140
160
180
200
DISTANCE FROM TRACKS IN FEET

fig. 1

At frequencies below eighteen (18) cycles per second and typically below ten (10) cycles per second whole structure response may occur if sufficient energy is present at the whole structure natural resonant frequency. Such response is typically evidenced by a swaying motion in loose or free hanging objects such as chandeliers or ceiling fans. This type of response was noted during this study in response to an extremely long freight train moving at forty (40) miles per hour. In this case the length of the passing train combined with the extended output of vibrations possessing peak energy, 0.03 inches per second, at eight (8) cycles per second provided sufficient time for the structure to build up to a response at its natural frequency. All other rail traffic had a much shorter duration as it passed the test structures and produced insufficient energy at these lower frequencies to produce whole structure response.

As with ground vibrations, structural response was measured by placing several Everlert Ve seismic recorders at various points throughout the test structure. As rail traffic passed the structure vibrations were simultaneously collected from the ground adjacent to the structure as well as on the exterior walls, interior walls, all floor levels and in the attic.

In all cases with the exception of the extremely lengthy heavy freight discussed previously interior responses to rail induced ground vibrations fell at or below levels of human perception. Even at these very low vibration levels, in some cases it was noted that freight trains and some Amtrack traffic produced audible responses from free hanging objects on interior walls. Such responses typically go unnoticed if the responding wall is free of pictures and/or other loose objects.

Sound levels recorded from 35 to 40 mile per hour Amtrack, light commuter, and heavy freight trains during this portion of the study were collected at distances of from one-hundred (100) to two-hundred and fifty (250) feet from each type of rail traffic. These distances represent the typical range of homes found along the Decatur Belt whose occupants stated that they could always hear present rail operations.

Present Decatur Belt traffic measured during this and our previous study ranged from 62 dbA for a single engine pass-by to 68 dbA for an engine and eight (8) to ten (10) loaded cars moving approximately fifteen (15) miles per hour. As noted in the introduction to this report, two (2) apparently new model Amtrack engines were also observed sitting at idle on the Decatur Belt to the rear of the Sybil Smith residence at 1758 Flagler Drive. The combined sound level produced by these engines resulted in a reading of 72 dbA at a distance of one-hundred and fifty (150) feet from the rail line. During the hours of present Decatur Belt rail operation (eleven o'clock (11:00) AM. and four o'clock (4:00) PM.) typical neighborhood ambient sound levels in the presence of no rail traffic fell predominantly in the 55 to 65 dbA range.

Pass-by sound levels measured in the presence of 35 to 40 mile per hour Amtrack trains at distances of one-hundred (100) to two-hundred and fifty (250) feet from the test area ranged from seventy-one (71) to eighty (80) dbA.

Typical pass-by sound levels recorded from light commuter traffic for similar distances and speeds near the Lancaster, Philadelphia area produced readings ranging from 60 dbA to 71 dbA. Trains were composed of one (1) engine and three (3) to four (4) full passenger cars.

Heavy freight pass-by levels recorded approximately a quarter (1/4) mile North of the Brookwood Rail station ranged from seventy-five (75) to eighty-three (83) dbA. Trains were composed of two (2) to three (3) engines and fifteen (15) to thirty-five (35) loaded cars.

Fourier frequency analysis of peak segments of sound level wave forms revealed that both Amtrack and heavy freight traffic have distinct energy concentrations in two (2) frequency ranges. It was found that the primary energy content was centered around the ninety (90) to one-hundred and twenty (120) cycle per second range. A secondary peak was also noted at the three (3) to ten (10) cycle per second level.

As with ground vibrations, low frequency air borne wave forms may cause sympathetic reverberation of structures or of individual structural components. Although the energy content of the three (3) to ten (10) cycle per second sound level wave forms discussed above is insufficient to cause whole structure resonance, it is sufficient to cause humanly perceptible movement in large panes of window glass, expansive roofs and walls. Present Decatur Belt sound level wave forms also posses energy concentrations in the five (5) to thirty-five (35) cycle per second range however the level of energy and the duration of influence on individual structures is insufficient to cause noticeable levels of reverberation.

Conversation with home owners along the Decatur Belt suggests that such structural reverberation is not a typical problem with present rail traffic and was not detected by Vibra-Tech at any of the test locations in this area. Past experience with similar projects indicates that such reverberations can be objectionable to some home owners and is often a primary source of complaints.

Fourier analysis of sound level wave forms collected from light commuter trains indicates primary energy concentration in the one-hundred and ten (110) to one-hundred and thirty (130) cycle per second range. In comparison almost no low frequency energy was noted suggesting that commuter rail traffic may be less noticeable structurally than the other forms discussed in this study.

In general it was found that as the speed of the trains observed in this study increased, there was an associated shift in the predominant energy content toward higher frequencies for both ground and air borne vibrations. An over all increase in the level of energy produced also occurred with increased speed for all types of rail traffic in the study.

DISCUSSION OF RESULTS: TASK 2

During this phase of the study existing "A" weighted ambient sound levels were collected adjacent to eight (8) typical residential structures located in the test area. This data is intended to allow a comparison between the percentage of time that sound levels from future rail traffic may impact structures with that of present rail traffic. A comparison may also be made between the percentage of time that structures are impacted by typical neighborhood sound levels and that of future commuter and Amtrack traffic. Present ground vibration levels from existing Decatur Belt rail traffic were also collected at this time.

Sound level recording locations were selected to sample as broad as possible range of neighborhood sound including both day and night time conditions. Each of the eight (8) recording locations have been marked on the site map labeled fig. 2 on the following page of this report. The location numbers found on this map coincide with the individual data plots in the appendix to this report labeled 2-A through 2-H. The names and addresses of home owners have also been included on each data plot.

The actual recording and analysis of ambient sound level data was accomplished with the General Radio model 1945 Community Sound Level Analyzer. This instrument is capable of measuring, storing and analyzing "A" weighted sound levels for three (3) separate, user programmable time periods from a half (1/2) to twenty-four (24) hours in length. The analysis of each time period provides a maximum decibel level, Lmax, a minimum level, Lmin, an average level, Leq, and percent exceedance levels for various percentages of time during each recording period based on the total length of the period.

During this study the model 1945 analyzer was programed to record a six (6) hour period from 12:00 AM to 6:00 AM, a twelve (12) hour period from 6:00 AM to 6:00 PM, and a second six (6) hour period from 6:00 PM to 12:00 AM. This recording procedure was employed for all eight (8) recording locations in this study. The appended data plots 2-A through 2-H graphically show the results from each of the previously mentioned periods for each of the recording locations.

Sound levels generated in residential neighborhoods are particularly likely to be the summation of the effects of a large number of sound sources, each influencing the surrounding area for indefinite amounts of time. Therefore, the total sound impacting nearby homes is likely to have wide variations throughout a given period of time such that it cannot be easily characterized by a single number sound level reading.

Exceedance level calculations are used to characterize fluctuating sound levels on a statistical basis. The "X" percent exceedance level is the sound level in dbA exceed "X" percent of the time. This exceedance is usually symbolized as Lx ; for example, "L10 = 68 dbA" means that for ten (10) percent of a set data recording period, say 6:00 AM to 6:00 PM, the sound exceeds a level of 68 dbA. Lmax is the sound level that is never exceeded while Lmin is exceeded one-hundred (100) percent of the time.


Ponce De Leon Baptist
WESLEY ROAD
Garden Hills Park
Cathedral of Christ the King
PEACHTREE HGTS EAST
Parkside Drive Park
Alexander Park
BROADVIEW-MOROSGO
INDIAN CREEK
MARIAN ROAD
Lindbergh Center
Broadview Plaza
Exit-30
LINDBERGH
Covenant Presb
E Rivers ES
PEACHTREE HILLS
Peachtree Hills Park
PEACHTREE MEMORIAL DR
Peachtree Battle Shop Ctr
CREEK
LAKESHORE DR
MORNINGSIDE-MARTIN MANOR
Exit-28
ATLANTA
BROOKWOOD HILLS
Dale Way Park
PIEDMONT HEIGHTS
CHESHIRE BRIDGE
Exit-27
Rock Springs
MORNINGSIDE-LENOX PARK
Lenox-Wildwood Park
Sherwood Forest
Atlanta Masonic Temple
Ansley Golf
Peachtree Ch
Ansley Mall
Sussex Park
ROCK SPRINGS ROAD
Morningside ES
Exit-26
Exit-25
ANSLEY PARK
Ansley Park
McClatchey Park
Winn Park
First Church of Christ Scientist
COLONY SQUARE
Atlanta Memorial Arts Ctr
PIEDMONT PARK
Piedmont Lake
Exit-102
Exit-101
MIDTOWN
Henry Grady HS
VIRGINIA HIGHLAND
FULTON COUNTY
DOWNTOWN CONNECTOR
PIEDMONT AVENUE
1A
1B
1C
1D
1E
1F
1G
1H
1010
1030
1074
C
D5
E
F
G
3
4
8
9
FIG-2

To more easily view the exceedance level data collected from locations 2-A through 2-G an average plot of all eight (8) locations has been produced on the following page as fig.3. Looking at this plot, it can be seen that L10 sound levels typically remained below a 55 to 60 dbA night/day range except for ten (10) percent of each of the three (3) monitoring periods. Assuming the six (6) and twelve (12) hour periods employed in this study, this would indicate that for thirty-six (36) and seventy-two (72) minuets, respectively the sound level exceeded the 55 to 60 dbA range.

For the L1 level it can be seen that the night/day range is slightly wider (62 to 70 dbA) with respective exceedance levels corresponding to 3.6 and 7.2 minuets for one (1) percent of each period. With the L1 levels in mind, present Decatur Belt rail traffic produces average sound levels of 64 dbA and impacts each residence for a period of thirty (30) seconds to one (1) minuet depending on the length, speed and number of trains passing during a recording period.

A proposed Amtrack train would produce an average sound level of 75 dbA with a maximum impact duration of approximately eight (8) to fifteen (15) seconds (depending on the length, speed and number of trains passing during a recording period) per residence passed at 35 to 40 miles per hour. Commuter traffic produced an average level of 68 dbA with a slightly shorter impact duration. Fig.3-A shows the same average ambient sound level exceedance levels taken from fig.3 along with the average sound levels produced by various rail traffic measured during this study.

Assuming the relatively short impact duration of the trains monitored during this study as compared to the duration of typical neighborhood sound sources such as lawn mowers, weed eaters and leaf blowers, the proposed addition of Amtrack and light commuter rail traffic To the Decatur Belt would appear to be of little consequence from purely a sound level stand point.

It should be noted however that Amtrack traffic appears to produce slightly higher sound levels than freight traffic at similar distances and speeds. Fourier analysis of sound level wave forms collected from Amtrack and heavy freight indicates that Amtrack wave forms posses considerably more high frequency secondary energy above the ninety (90) to one-hundred and twenty (120) cycle per second peak energy range than the heavy freight wave forms.

In field observations indicate that to the human ear, Amtrack engines tend to produce higher pitched sound levels than do freight engines. It was also noted that passenger cars tend to produce higher pitched wheel sound levels than do heavily loaded freight cars. Such differences in pitch are quite discernible to the human ear and in may often account for complaints received from near by home owners who have grown accustom to a certain type of sound. Even at identical decibel levels, most persons will tend to be more annoyed by an increase in the pitch of a sound than a decrease.

AVERAGE EXCEEDANCE LEVELS FOR AMBIENT SOUND LEVELS COLLECTED FROM LOCATIONS 1-A TO 1-H

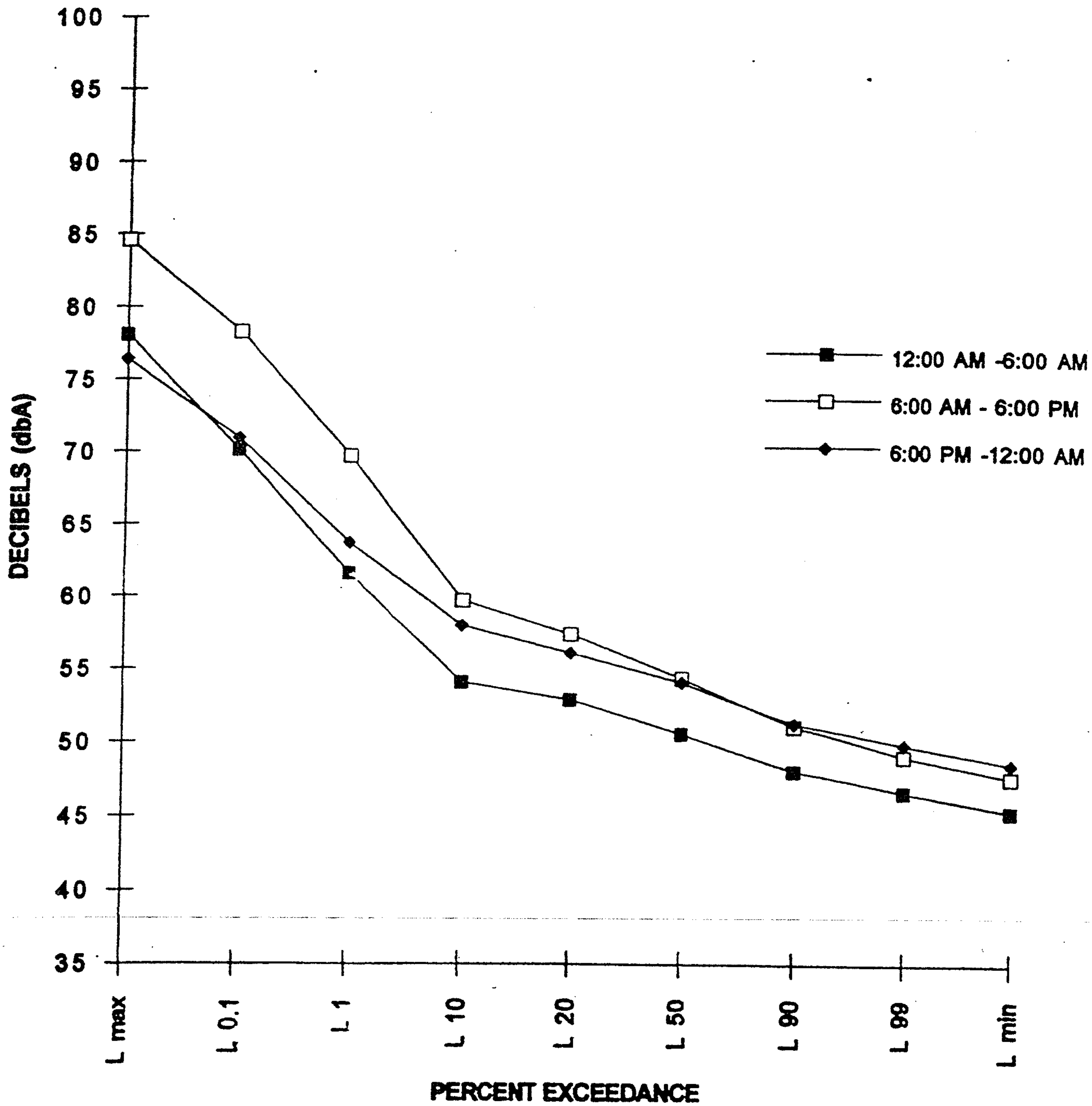


fig. 3

AVERAGE EXCEEDANCE VALUES FOR EXISTING AMBIENT SOUND LEVELS RECORDED AT LOCATIONS 1-A TO 1-H VERSUS TYPICAL SOUND LEVELS PRODUCED BY VARIOUS RAIL TRAFFIC RECORDED AT 150 FEET

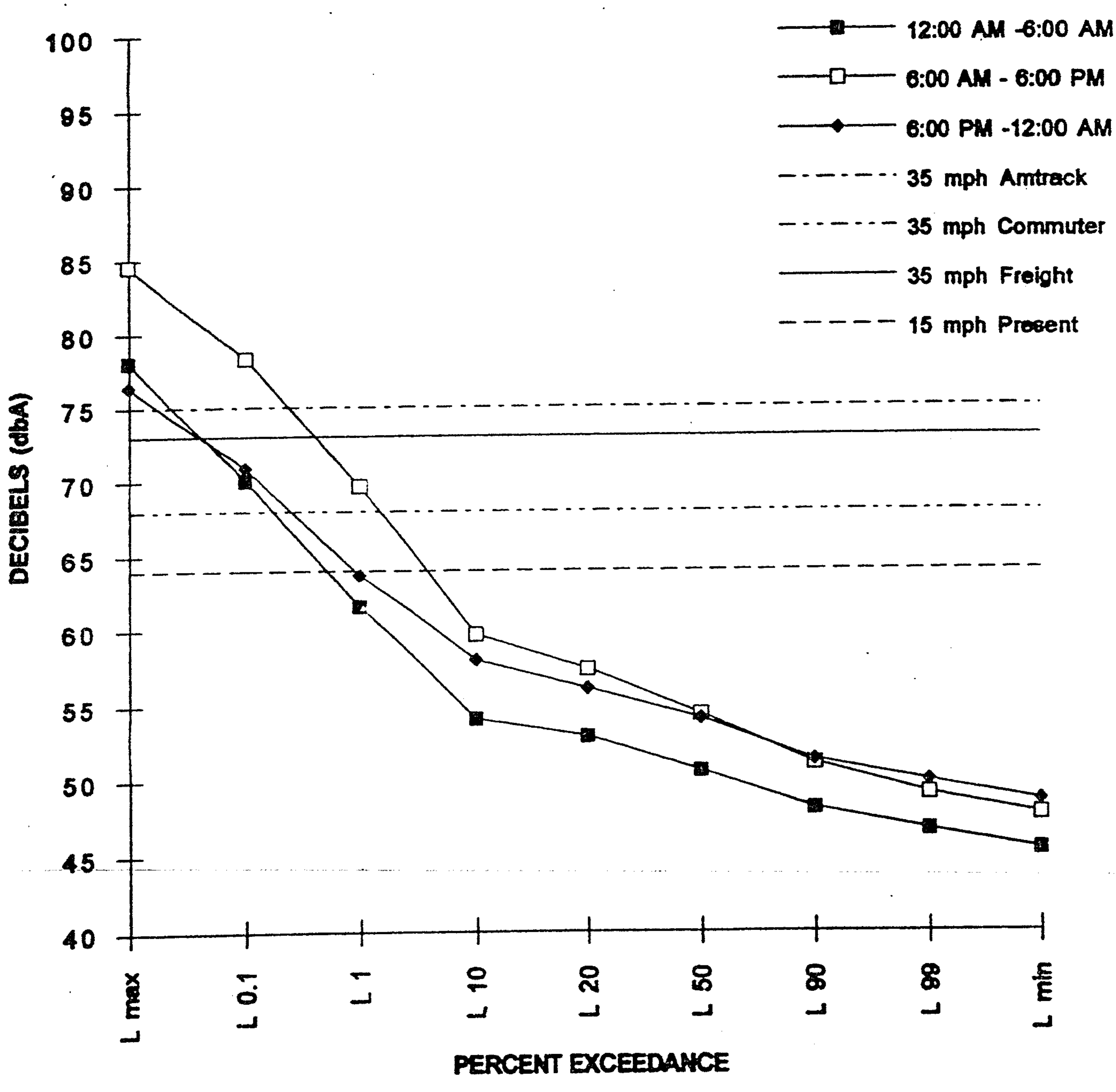


fig. 3A

Seismic data collection from existing Decatur Belt rail traffic was accomplished in a similar manner to the collection of off site Amtrack and heavy freight data.
A series of Everlert Ve seismic recorders were placed on the ground extending away from the Decatur Belt rail line at intervals of twenty (20) feet. The nearest instrument was consistently placed approximately ten (10) feet from the track and generally lay at the point of contact between the ground and stone ballast beside the tracks. In all cases, eleven (11) instruments were used to achieve a distance of two-hundred (200) feet with an additional instrument placed at two-hundred and fifty (250) feet to confirm attenuation of vibrations below the instruments operable lower end resolution of 0.001 inches per second. This procedure was conducted at locations 1-A, 1-C, and 1-D as listed on the previously mentioned site map (fig.2).

In order to collect data beyond approximately the eighty (80) foot interval, instruments were triggered manually as trains passed due to vibration levels falling consistently below the instruments lowest self triggering setting of 0.005 inches per second.

Figure number one (fig.1) mentioned previously in this report graphically represents the findings of this portion of the study in comparison to similar data collected for Amtrack, light commuter and heavy freight rail traffic. As can be seen, there is little difference between the vibration levels recorded on the ground at distances of one-hundred (100) feet or greater with vibrations typically falling below the levels of human perception. A brief survey of the study area and the entire Decatur Belt indicates that very few structures fall within the one-hundred (100) foot distance of the track. Several residential structures were noted at distances of one-hundred and twenty (120) to one-hundred and fifty (150) however most were found to be two-hundred (200) feet or greater in distance.

Based on the above, it is highly unlikely that the addition of Amtrack or light commuter rail traffic will actually be any more noticeable to near by home owners, from a purely ground vibration stand point, than present Decatur Belt rail traffic.

Although most people believe that rail traffic produces considerable amounts of far reaching ground vibration, it has been Vibra-Tech's experience that much of what people perceive as ground vibration is actually associated with both the audible and inaudible low frequency portion of the sound spectrum produced by the engines. As discussed in task 1, low frequency sound is quite capable of causing reverberations of various structural components in residential homes. Unlike sound where humans appear to become increasingly annoyed with increasing pitch and higher frequencies, ground vibrations and induced structural vibrations tend to become most noticeable and increasingly annoying as frequencies become lower. For this reason, At very low inaudible frequencies, it is often difficult for the human body to discern actual sound induced vibrations from ground borne wave forms. This may account for much of the confusion the seismologist may encounter from the lay person when he reports that the ground borne vibrations that he has recorded with his seismograph are below levels of human perception and yet this person knows that he is feeling something.

DISCUSSION OF RESULTS: TASK 3

This portion of the study was intended to determine the actual response of structural components of several typical residential homes in the study area to the present Decatur Belt rail traffic. As with ground vibrations, structural response would be measured by placing several Everlert Ve seismic recorders at various points throughout the test structure. As rail traffic passed the structure, attempts were made to simultaneously collect vibrations from the ground adjacent to the structure as well as on the exterior walls, interior walls, all floor levels and in the attic.

Several attempts were made with instruments set up at one of the closest structures to the Decatur Belt, location 1-A, to record induced structural vibrations from passing trains. During all attempts, trains appeared to be moving at speeds below ten (10) miles per hour and were noted to be moving empty or lightly loaded cars. Such activities producing ground vibrations at or below the lower end resolution of the Everlert Ve recorders, 0.001 inches per second, with frequencies below the dynamic limits of the sensors employed, 2 cycles per second. Such low levels of vibration are incapable of producing any form of measurable structural resonance due to the low energy content and frequencies that fall out side of the natural resonant frequencies of most residential structures and components thereof.

The slower than anticipated speeds of trains encountered during this portion of the study also resulted in relatively low levels of sound energy arriving at the test site. For this reason no sound induced structural reverberations were detected at any time.

However, seismographs placed at various points within this test structure reported vibrations of from 0.001 to 0.45 inches per second in response to typical house hold activities conducted by the home owner during these tests. In combination with the structural response findings discussed in Task 1, it is believed that such typical in house vibrations will have a much greater impact on the structures along the Decatur Belt than the vibrations produced by the proposed future addition of Amtrack and light commuter trains to this line.

DISCUSSION OF RESULTS: TASK 4

In order to determine the site specific characteristics of the local soils found between the Decatur Belt and adjacent test structures, geophysical tests employing seismic refraction techniques were conducted. Once such characteristics have been determined, the impact of representative vibrations collected from other sources may be projected.

In general, these tests provided a transmission factor for soils in the study area that allowed for the development of site specific attenuation curves for various frequency ranges of ground vibrations traveling between the Decatur Belt and adjacent residential structures. These attenuation curves may be found in figure 4 on the following page of this report.

SITE SPECIFIC ATTENUATION OF GROUND VIBRATIONS BETWEEN THE DECATUR BELT RAIL LINE AND ADJACENT RESIDENTIAL STRUCTURES

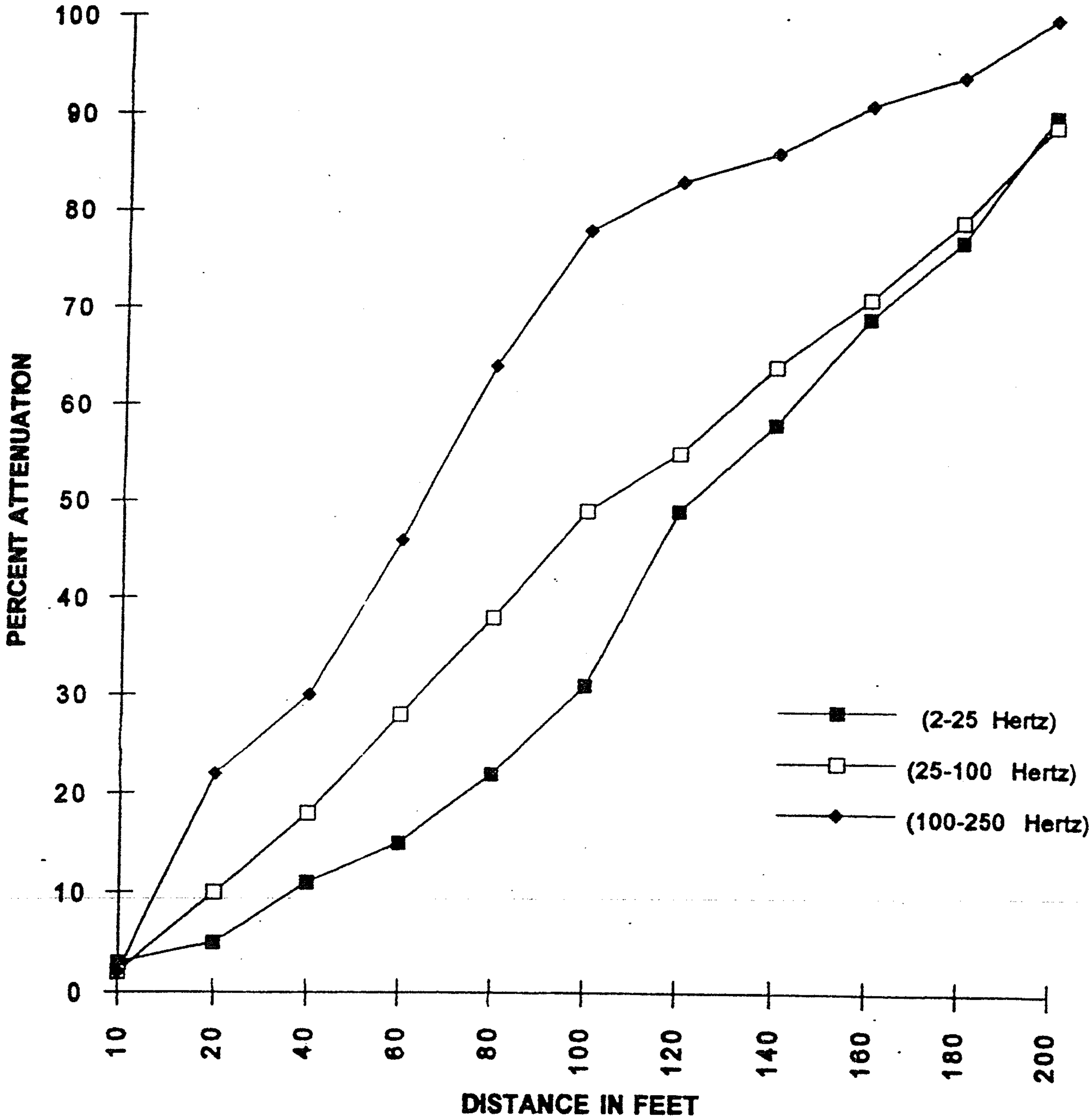


fig. 4

Similar tests procedures were also employed at the off site test locations for the recording of Amtrack, heavy freight and light commuter rail traffic. This was done to verify the existence of similar soil conditions to those found along the Decatur Belt prior to the collection of data in these areas.

The collection of data for this portion of the study was accomplished by placing a series of Everlert Ve seismic recorders at twenty (20) foot intervals between the Decatur Belt tracks and representative test structures in the study area. In each case a total of eleven (11) recording units were employed over a distance of two-hundred (200) feet. This procedure was conducted at locations 1-A, 1-C, 1-D, and 1-F.

In order to impart a constant amount of energy into the ground, a standard weight of fifty (50) pounds was dropped from a consistent height of ten (10) feet for each recording. The weight was allowed to strike the ground at a distance of ten (10) feet from each end of the series of seismic recorders. This procedure was continued until the soil in the drop area was sufficiently conditioned and consistent readings were received from several successive drops.

Arrival times between each seismic unit were calculated from the recorded data to determine the transmission velocity of the soils in each of the four (4) recording locations. It was found that the velocity of the soils adjacent to the Decatur Belt ranged from approximately twelve-hundred and fifty (1250) to fourteen-hundred (1400) feet per second. It should be noted that these velocities are representative of only the first ten (10) to twenty (20) feet of soil overburden due to the shallow exploration techniques employed for this survey. Past experience with seismic sensors buried at depth near other railroads suggest that rail induced vibrations typically travel in the upper five (5) to ten (10) feet of soil with little or no energy traveling below this level. For this reason, it is believed that the determination of near surface transmission velocities is adequate to describe the zone of attenuation in this study.

Seismic attenuation of vibrations traveling through a soil are governed by the transmission velocity of the particular soil and the frequency content of the passing wave form. In general, lower velocity soils tend to transmit vibrations of predominately low frequency content more readily and with a lesser degree of attenuation than do high velocity soils. The opposite is true of higher velocity soils in that they tend to maintain higher frequency wave forms and allow for the quick attenuation of lower frequencies.

For this study the attenuation of test vibrations have been grouped into three (3) frequency ranges 2-25 Hertz, 25-100 Hertz, and 100-250 Hertz. Figure 4 shows the relative percent of attenuation of these frequency ranges over distance in response to our drop test. In this test situation there is no zero percent attenuation since the test weight was dropped at the ten (10) foot distance. Vibrations at this point consistently reached 1.650 inches per second. Complete attenuation in this case is defined by the lower end resolution, 0.001 inches per second, of the seismic recorders employed.

As can be seen, vibrations possessing peak energy in the range of one-hundred (100) to two-hundred and fifty (250) cycles per second tend to experience the quickest rate of decay as they travel through the soil adjacent to the Decatur Belt. Conversely, the lower frequencies tend to be sustained over a greater distance. As discussed previously, most residential structures tend to posses natural structural frequencies in the range of 2 to 25 cycles per second.

Since it has been found that the soils in the vicinity of the Decatur belt support these frequencies, humanly perceptible resonance of structures and /or components in response to ground borne vibrations would be possible if sufficient energy were present. It should be noted that our off site recordings of 35 to 40 mile per hour Amtrack, light commuter and most heavy freight rail traffic typically produced peak energy levels that coincide with the 2 to 25 cycle per second frequency range discussed above. Additionally, present Decatur Belt traffic centers much of its ground vibration energy in this range although energy levels were found to be totally insufficient to produce resonance of whole structures or of individual components.

The appended figures 5-A through 5-D are typical maximum ten (10) second duration seismic wave forms and frequency analysis collected respectively from present Decatur Belt traffic, light commuter, Amtrack, and heavy freight. All of these recordings were collected at a distance of one-hundred (100) feet from each type of rail traffic.

It should be noted that the type and condition of the track, jointed or seamless, determines to a great extent the amplitude of the vibrations produced and to some degree the predominant frequencies that are associated with the peak energy of a wave form. The typical seismograms and frequency plots presented in figures 5-B through 5-D were all recorded near seamless sections of rail that had been leveled and realigned within the past two (2) years. Recordings collected near poorly maintained jointed sections of track produced varying levels of vibration generally one half (1/2) to three (3) times as great as the levels presented in figures 5-B through 5-D.

Typically, the peak energy of wave forms collected near jointed track was found to be concentrated around a relatively narrow range of frequencies whereas seamless wave forms tended to distribute the total energy over a broader range of frequencies. Such distribution of energy over a range of frequencies will typically lessen the chances that a major portion of the wave forms energy will coincide with the natural resonant frequency of a near by residential structure. Although the chances are greater that a match will occur, the energy at the matching frequency would typically be insufficient to produce humanly perceptible structural reverberations.

It was also noted that the condition of the trains wheels had some bearing on both the ground vibration and decibel levels produced as a trains passed our recording locations. Generally, freight trains exhibited the highest number of cars with, "flat" spots on their wheels. On occasion Amtrack and commuter traffic was noted to have particular cars that produced atypical levels as compared to the rest of the train.

DISCUSSION OF RESULTS: TASK 5

The final task in our evaluation involved the statistical prediction of the effects that ground vibrations from added rail traffic may have on homes lying adjacent to the Decatur Belt Rail Line through the use of modal analysis techniques.

In order to conduct modal analysis a typical structure is chosen that has been determined to be representative of a majority of the homes in the impacted area. In this study the Sybil Smith residence located at 1758 Flagler Drive, location 1-D of figure 2, was chosen due to its similarity to other structures in the Ansley Park/Piedmont Heights area and to the willingness of Ms. Smith to allow us access to her home for several days.

Once a suitable structure is located, the exact measurements of the structure along with the types of building materials employed in its construction are programed into a computer such that an exact computer model of the structure may be created . Once the model is completed, typical rail induced vibrations recorded at a distance of ten (10) feet from heavy freight, Amtrack, and light commuter trains are applied to the model. As these wave forms interact with the model, the computer is requested to predict the response of the model and its individual structural components to these vibrations.

Since modal analysis deals with the frequency content of a wave form and not the amplitude, every attempt is made to collect the purest sample possible with little or no modification of the frequency content. This is typically accomplished by recording as close to the source of vibration as possible and still collect the sample as it travels through a medium representative of that that the test structure is founded on. The ten (10) foot recording distance generally falls at the edge of the stone ballast beneath the tracks and in an original soil zone.

The actual modeling of the structure and the final reporting of the results of this portion of our evaluation was conducted by Mr. Mohamad Sharifinassab who is a structural engineer located in Vibra-Tech's Louisville, Kentucky facility. Mr. Sharifinassab's findings are presented as a separate report included with this package.

CONCLUSION AND GENERAL CONSIDERATIONS

Based on the findings of tasks one (1) through four (4) of this study, it is Vibra-Tech's opinion that the addition of thirty-five (35) to forty (40) mile per hour Amtrack and/or light commuter rail traffic to the existing Decatur Belt Rail Line will have minimal ground vibration and/or sound level impact on the residential structures in the Ansley Park/Piedmont Heights area, Atlanta, Georgia.

This opinion is based on the assumption that the existing jointed tracks in the Ansley Park/Piedmont Heights area will be replaced with continuous non jointed rails and that train wheels will be properly maintained and are generally free of major flat spots and imperfections.

In general, the expected increase in speed of the Amtrack and light commuter trains combined with the weight differential and increased efficiency of operation between these and the present Decatur Belt freight trains should effect a much shorter impact duration on individual structures for both ground and air borne vibrations. Such reductions dramatically reduce the chances of an impacted structure reaching resonance at it's natural frequencies and in turn reduces the possibility of structural amplification of ground or air borne wave forms and the noticeability of such wave forms to the occupants of impacted structures.

Assuming a worst case scenario, the matching of predominant frequencies contained in rail induced ground and air borne wave forms with the natural resonant frequencies of residential structures along the Decatur Belt Rail line may produce short duration, humanly perceptible reverberations of loose fitting windows and doors, mild swaying of free hanging or standing objects, and possible buzzing or rattling of wall mounted pictures and bric-a-brac.

Our findings also indicate that in no case would the addition of Amtrack and/or light commuter trains to the Decatur Belt produce ground or air borne vibrations that would be considered structurally threatening to near by residential structures from a single pass or cumulative stand point. Such vibrations were also found to be totally incapable of producing cosmetic damages to the brick, drywall, stucco, plaster lath walls, ceramic tile surfaces and/or the general visible finishes employed on near by residential structures in the Ansley Park/Piedmont Heights area.

Sincerely,

Vibra-Tech Engineers

Randy W. Denman
Operations Manager

RWD:

Encl.

APPENDIX

Figures 2-A through 2-H
Percent Exceedance Versus Decibels (dbA)

Figures 5-A through 5-D
Typical Seismograms And associated Frequency Analysis

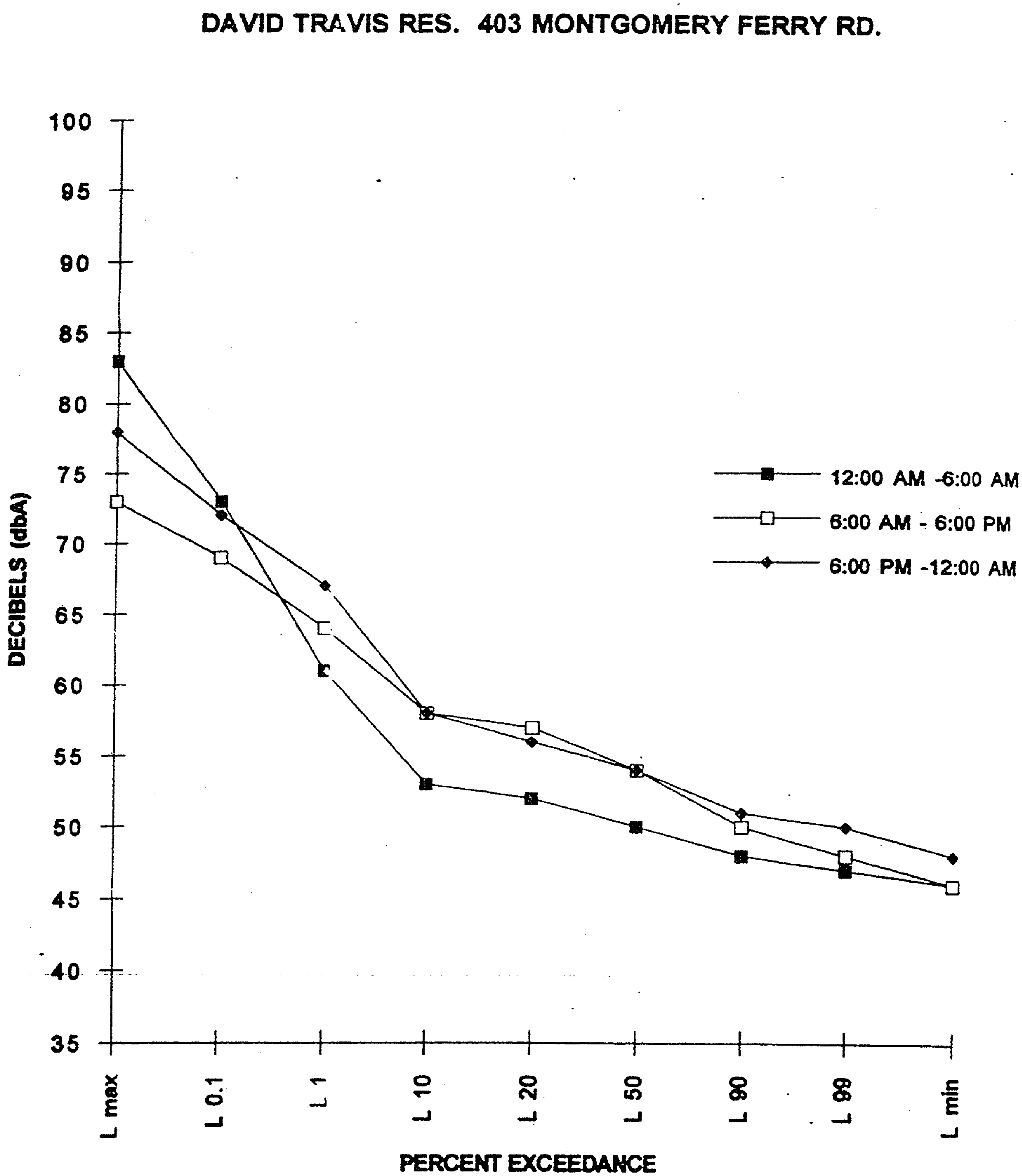

DAVID TRAVIS RES. 403 MONTGOMERY FERRY RD.
100
95
90
85
80
75
70
65
60
55
50
45
40
35
DECIBELS (dbA)
12:00 AM -6:00 AM
6:00 AM - 6:00 PM
6:00 PM -12:00 AM
L max
L 0.1
L 1
L 10
L 20
L 50
L 90
L 99
L min
PERCENT EXCEEDANCE

fig. 2A

ERIC LUND RES. 189 AVERY DRIVE

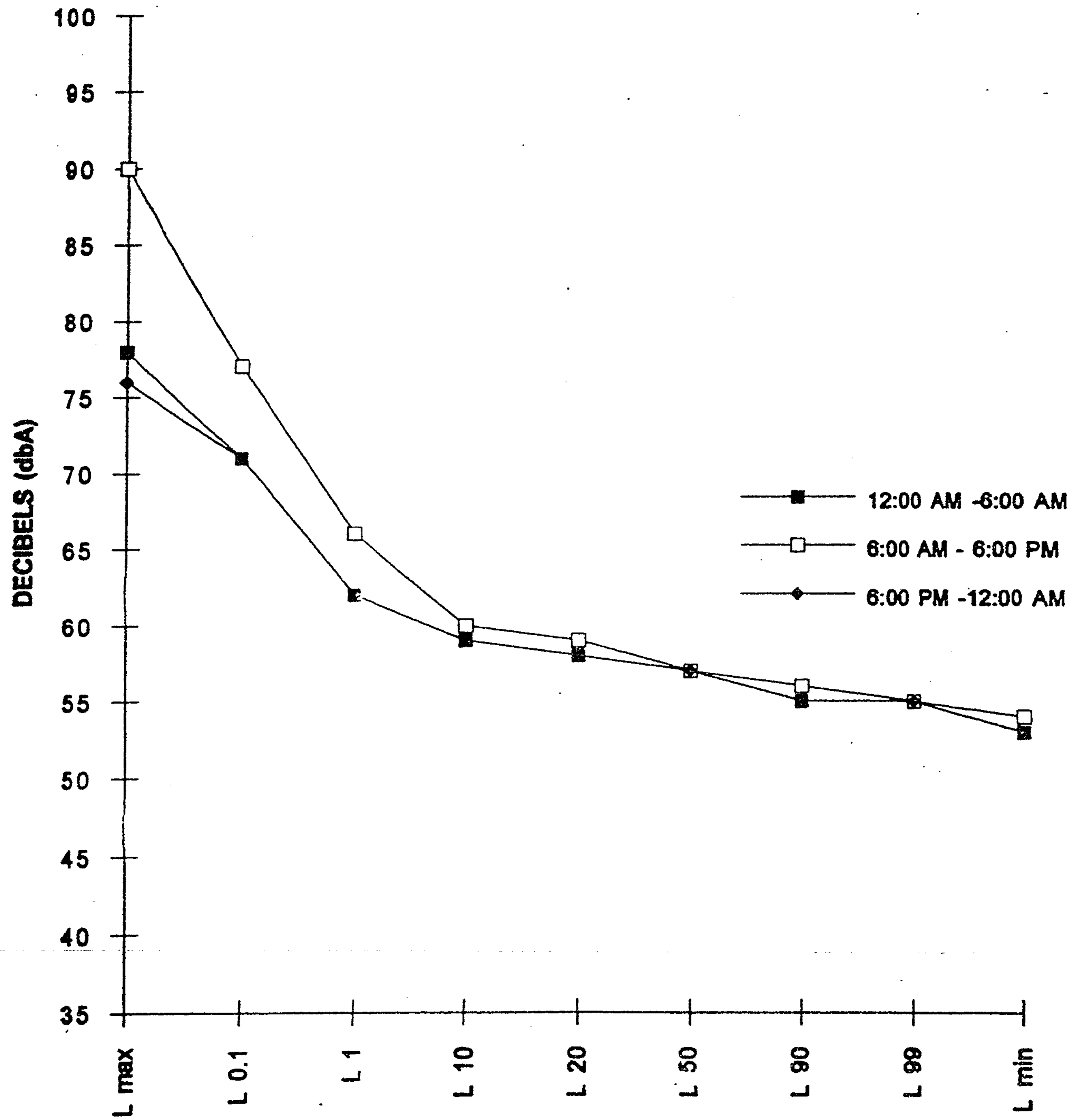


fig. 2B

SAM WAYMAN RES. 201 AVERY DRIVE

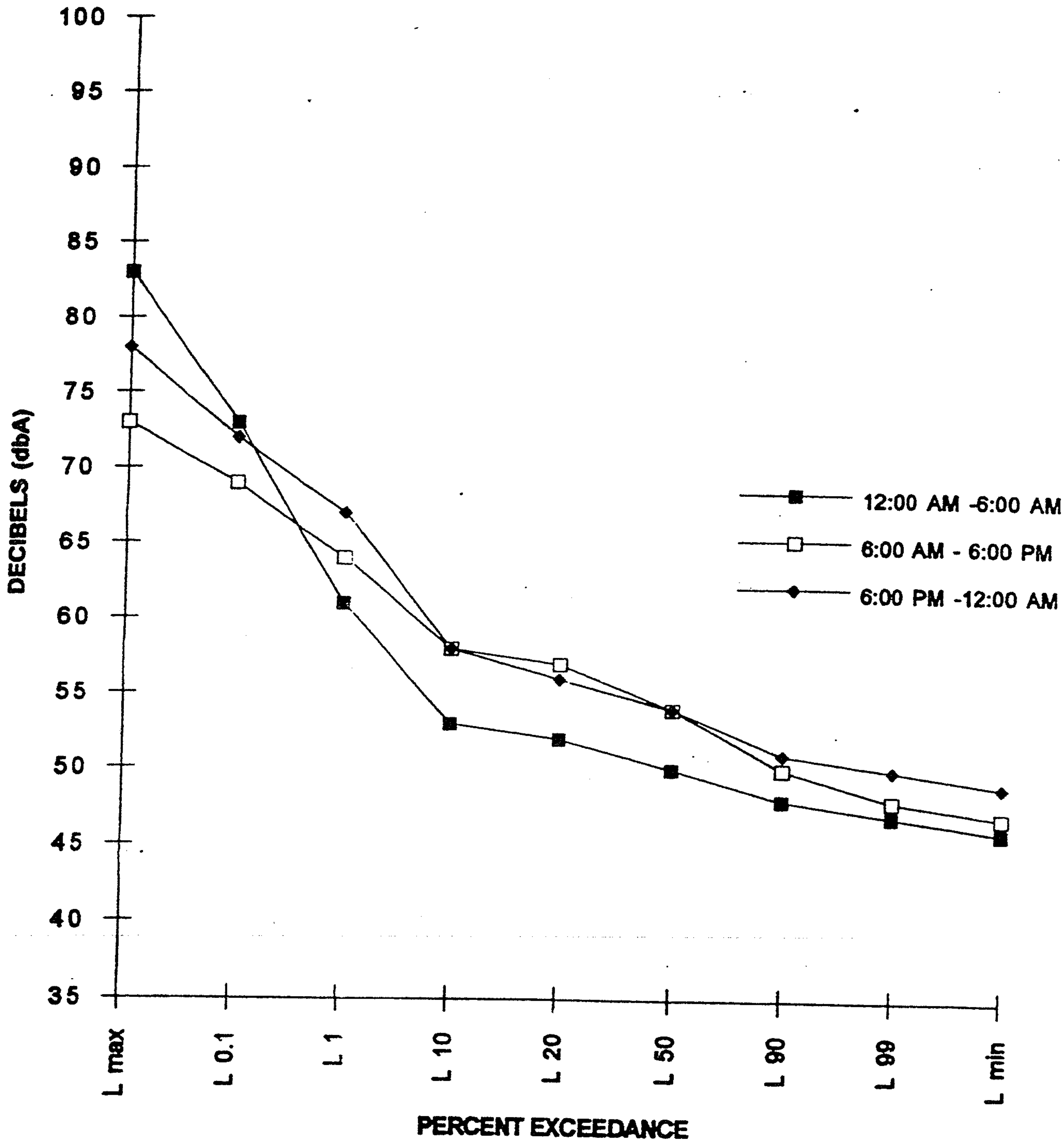


fig. 2C

SYBIL SMITH RES. 1758 FLAGLER AVE.

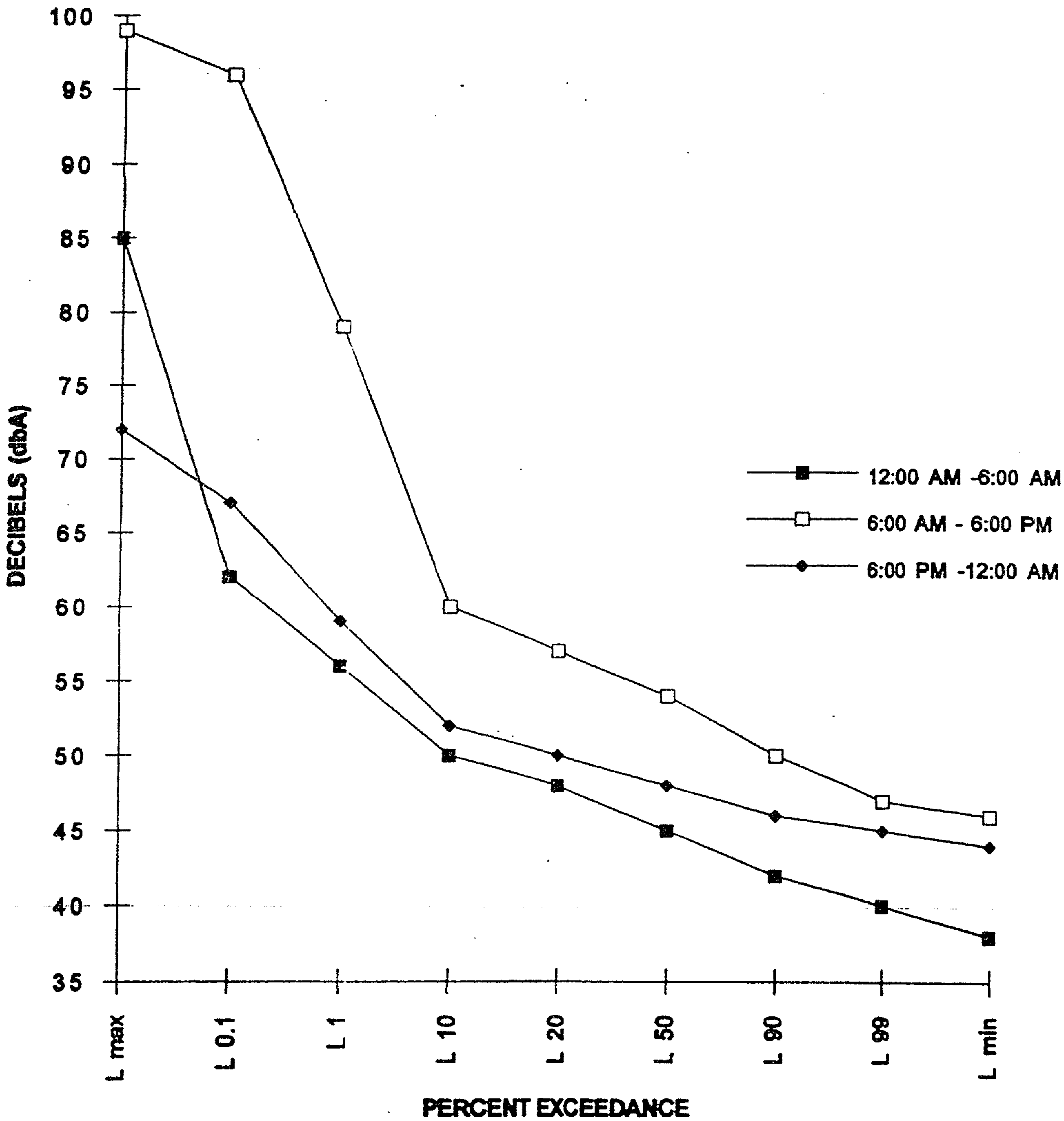


fig. 2D

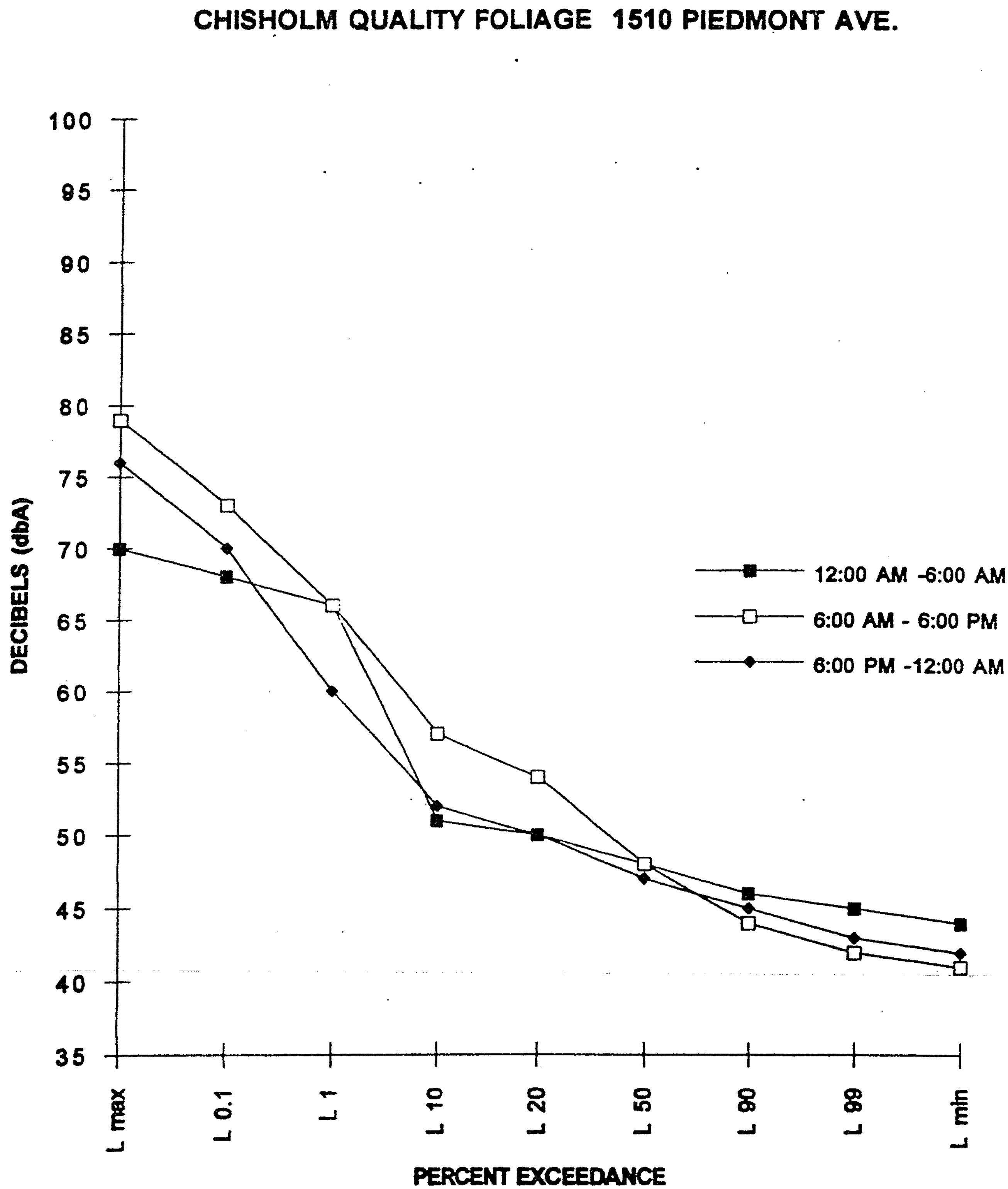

CHISHOLM QUALITY FOLIAGE 1510 PIEDMONT AVE.
DECIBELS (dbA)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
12:00 AM -6:00 AM
6:00 AM - 6:00 PM
6:00 PM -12:00 AM
L max
L 0.1
L 1
L 10
L 20
L 50
L 90
L 99
L min
PERCENT EXCEEDANCE

fig. 2E

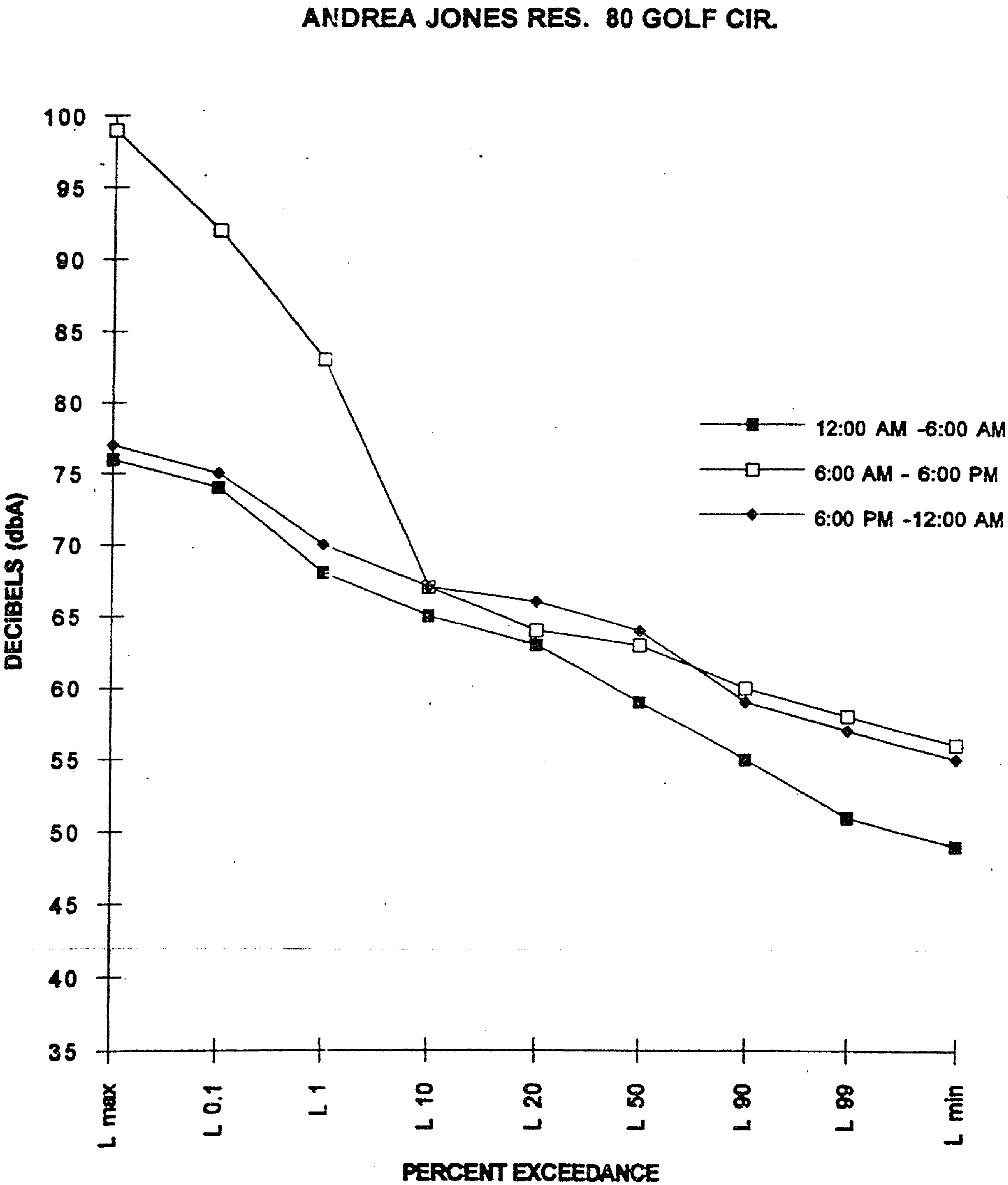

ANDREA JONES RES. 80 GOLF CIR.
DECIBELS (dbA)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
12:00 AM -6:00 AM
6:00 AM - 6:00 PM
6:00 PM -12:00 AM
L max
L 0.1
L 1
L 10
L 20
L 50
L 90
L 99
L min
PERCENT EXCEEDANCE

fig. 2F

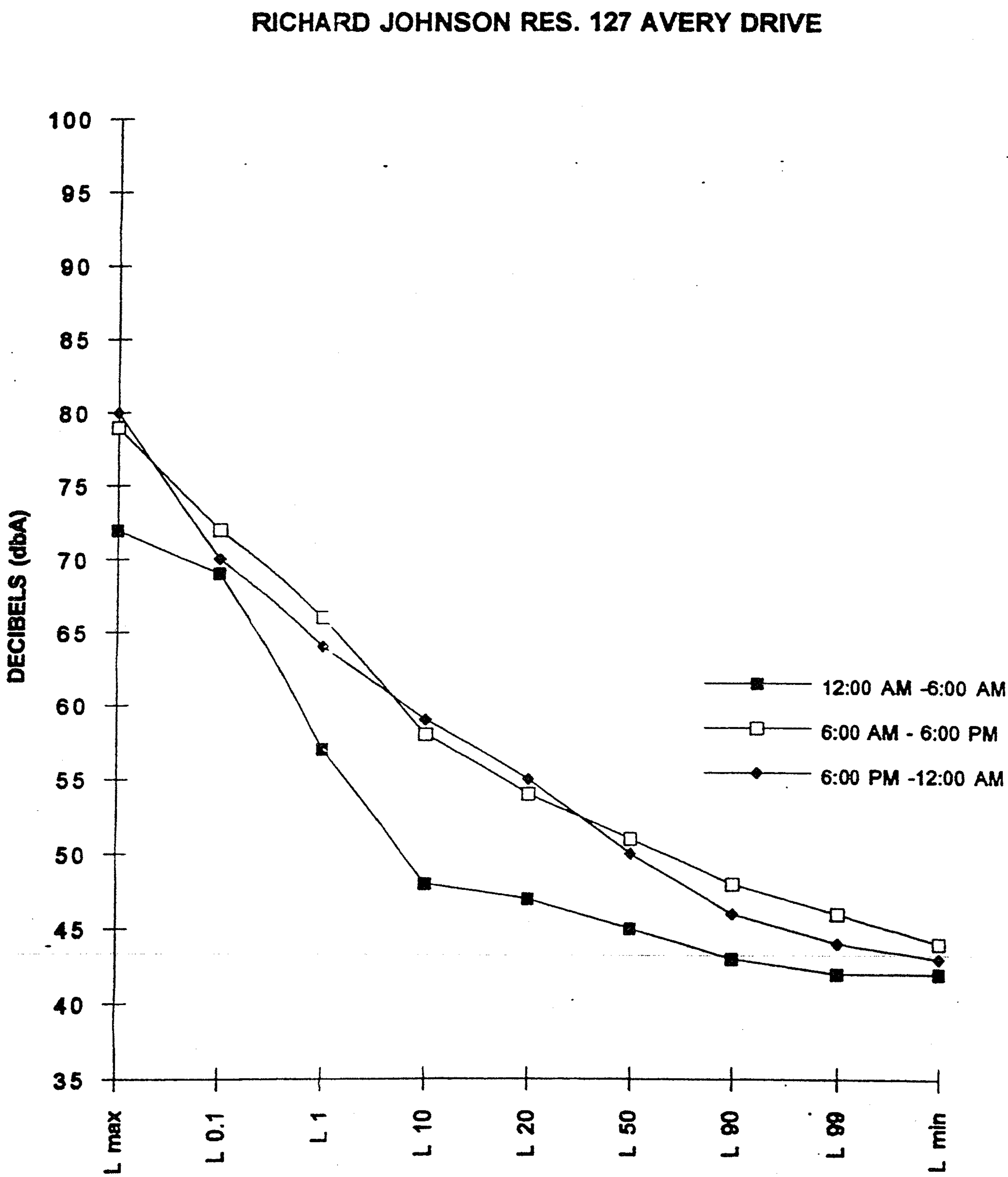

RICHARD JOHNSON RES. 127 AVERY DRIVE
DECIBELS (dbA)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
L max
L 0.1
L 1
L 10
L 20
L 50
L 90
L 99
L min
12:00 AM -6:00 AM
6:00 AM - 6:00 PM
6:00 PM -12:00 AM

fig. 2G

HARMON GRESHAM RES. 1800 FLAGLER AVE.

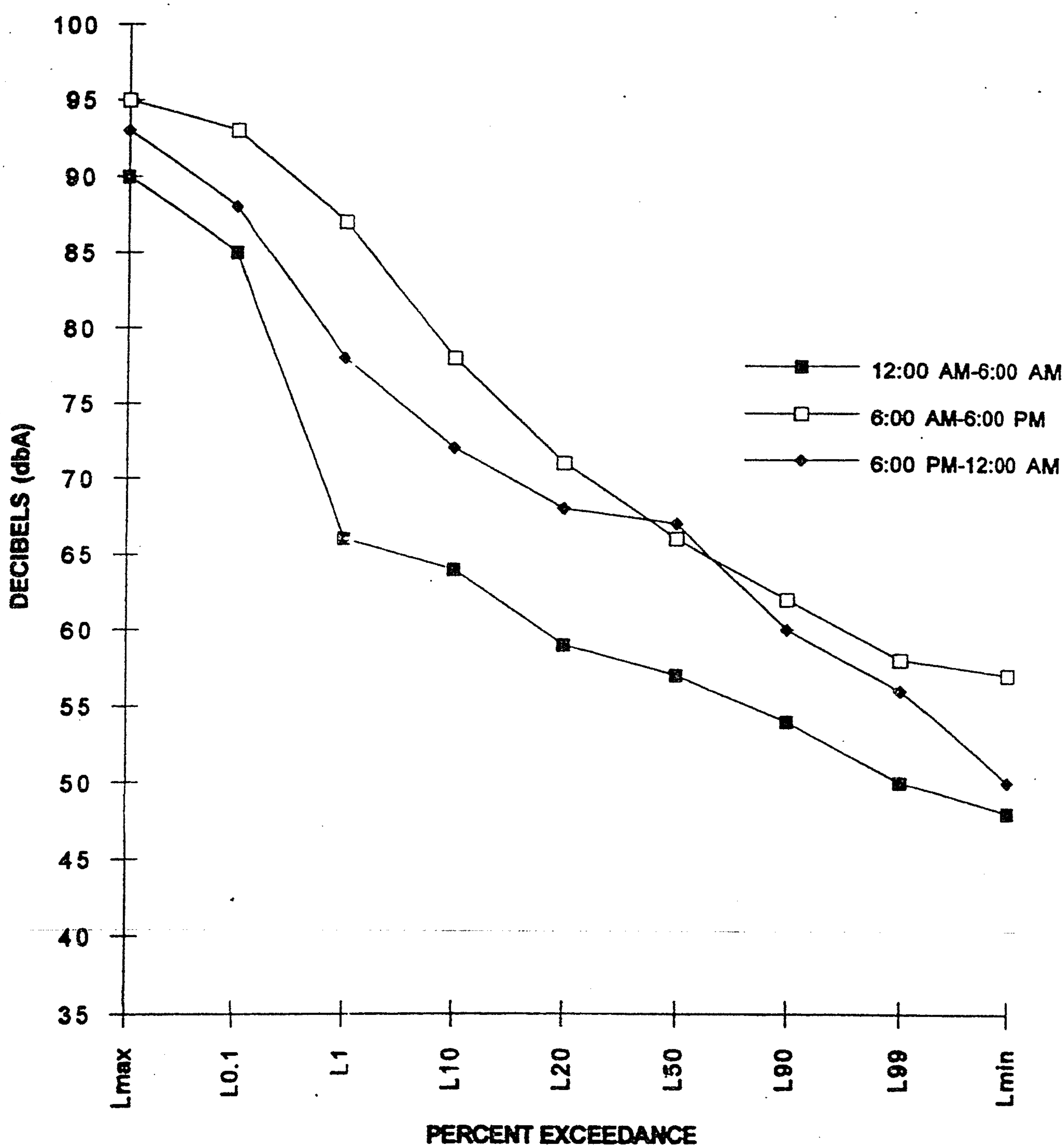
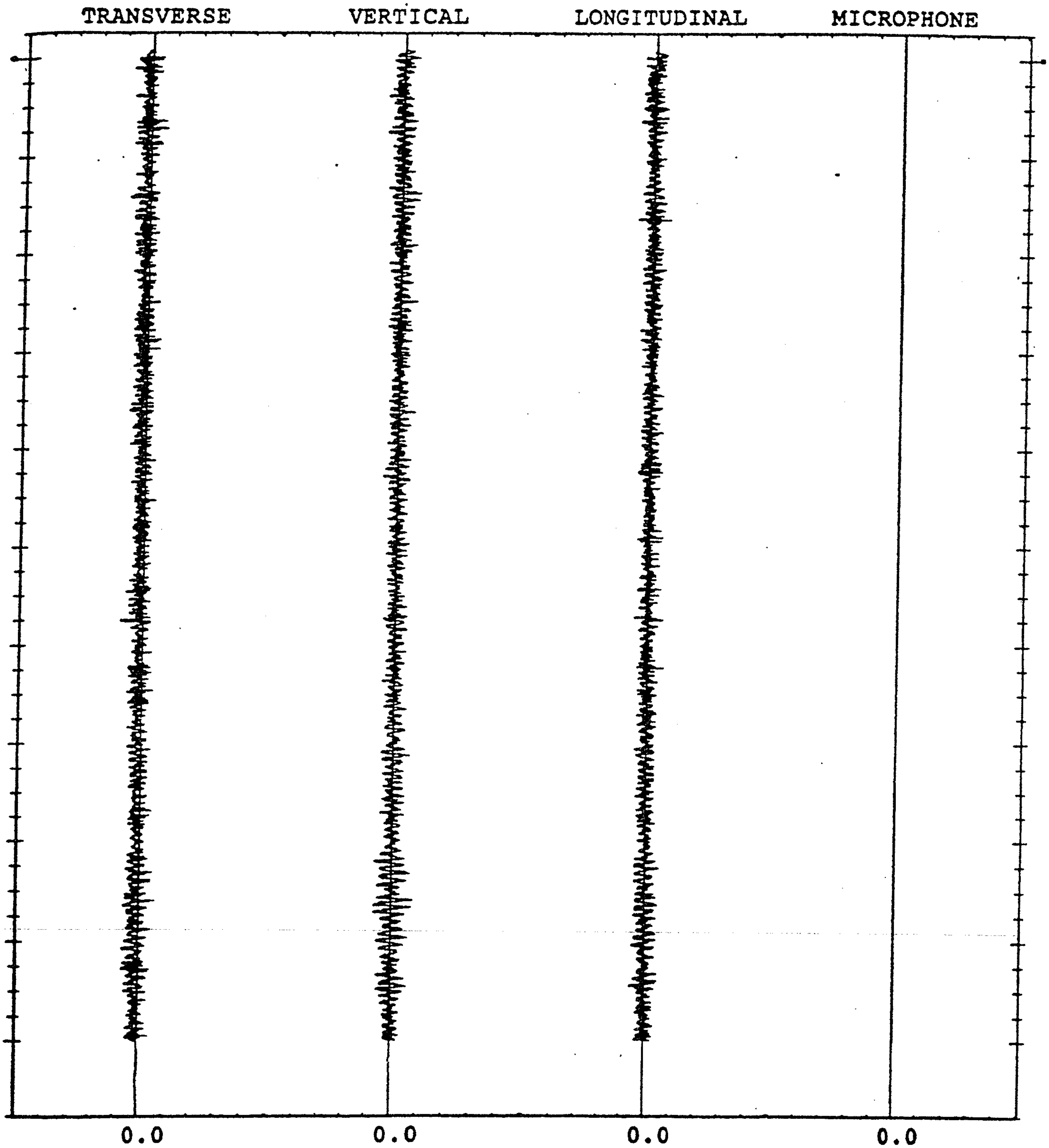


fig. 2H

FIGURE 5A
15 MPH PRESENT DECATUR BELT
T=0.009, V=0.008, L=0.007 IN/SEC.

CODE C80256A6.XWV **EVENT WAVEFORMS** PAGE # 1 of 1



AMPLITUDE SCALE:GEO: 0.010 in/sec/div MIC: 0.0200 psi(L)/div
TIME SCALE: 250 msec/div 10.981 sec/page TRIGGER =

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FIGURE 5-AA
15 MPH PRESENT DECATUR BELT
T=13 HZ, V=12 HZ, L=13 HZ

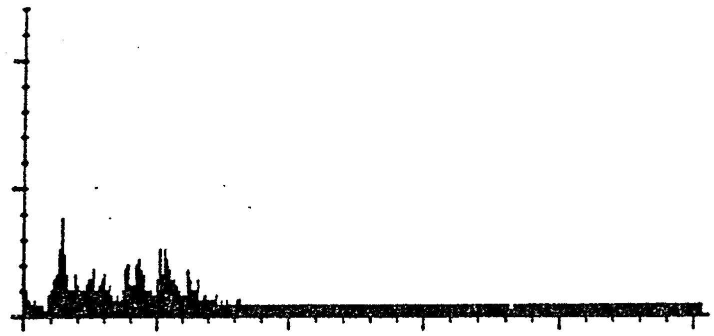
CODE C80256A6.XWV

FREQUENCY SPECTRUM

TRANSVERSE

Y AMPLITUDE:
0.0001 in/sec/div

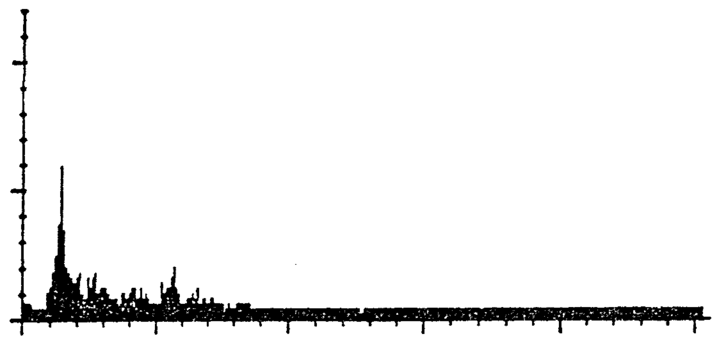
X FREQUENCY:
10 Hz/div



VERTICAL

Y AMPLITUDE:
0.0001 in/sec/div

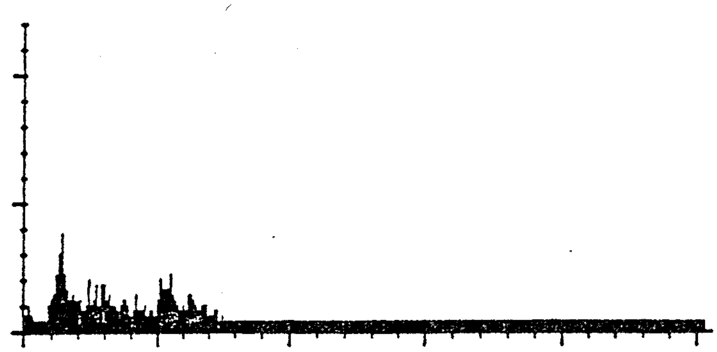
X FREQUENCY:
10 Hz/div



LONGITUDE

Y AMPLITUDE:
0.0001 in/sec/div

X FREQUENCY:
10 Hz/div



MICROPHONE

Y AMPLITUDE:
0.000002 psi/div

X FREQUENCY:
10 Hz/div

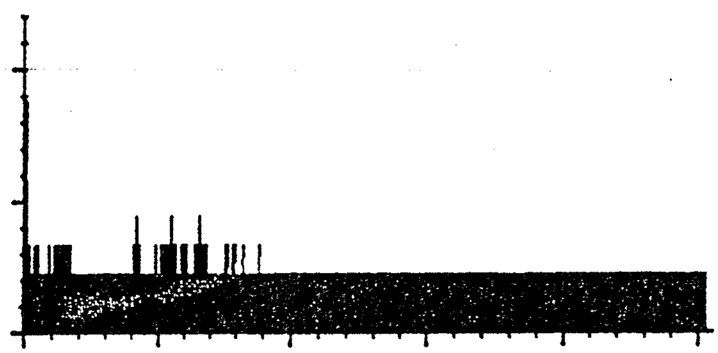


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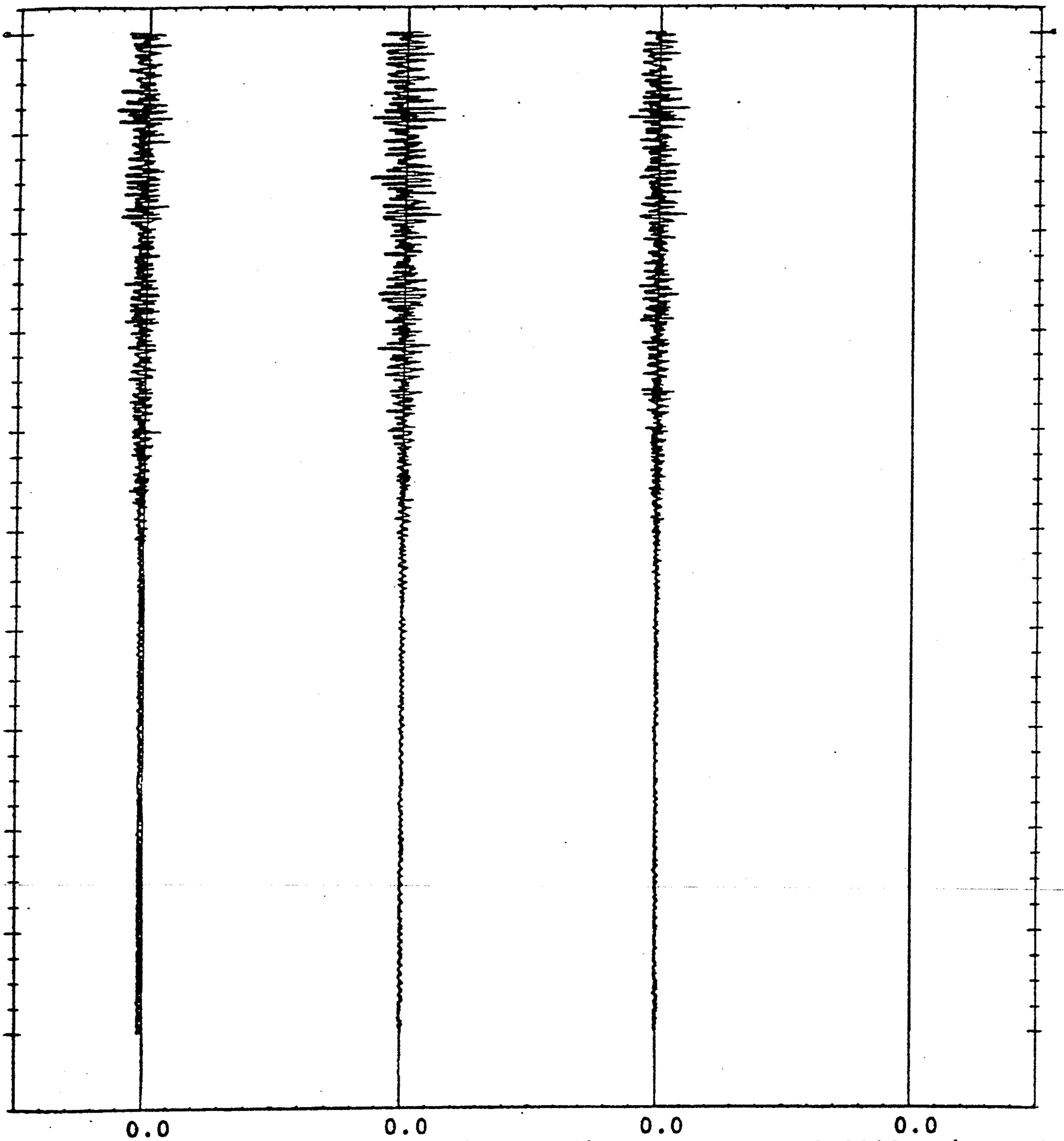
FIGURE 5-B
35 TO 40 MPH LIGHT COMMUTER
T=0.012, V=0.015, L=0.012 IN/SEC.

CODE C80256A3.EIV EVENT WAVEFORMS PAGE # 1 of 1



AMPLITUDE SCALE:GEO: 0.010 in/sec/div MIC: 0.0200 psi(L)/div
TIME SCALE: 250 msec/div 10.981 sec/page TRIGGER =

Vibra-Tech
THE VIBRATION MONITORING EXPERTS

FIGURE 5-BB
35 TO 40 MPH LIGHT COMMUTER
T=12 HZ, V=16 HZ, L=18 HZ

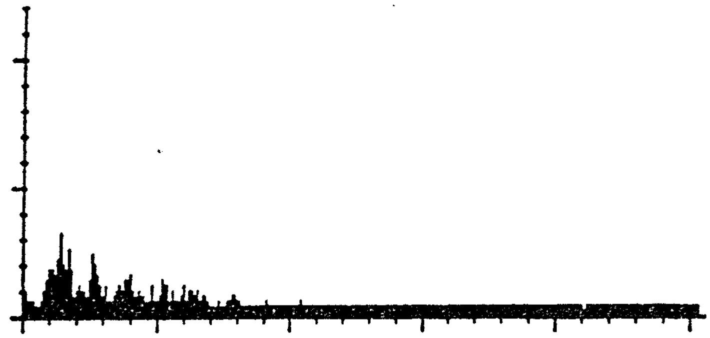
CODE C80256A3.EIV

FREQUENCY SPECTRUM

TRANSVERSE

Y AMPLITUDE:
0.0001 in/sec/div

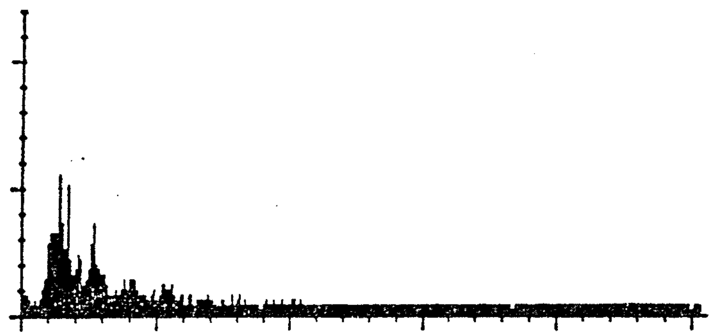
X FREQUENCY:
10 Hz/div



VERTICAL

Y AMPLITUDE:
0.0001 in/sec/div

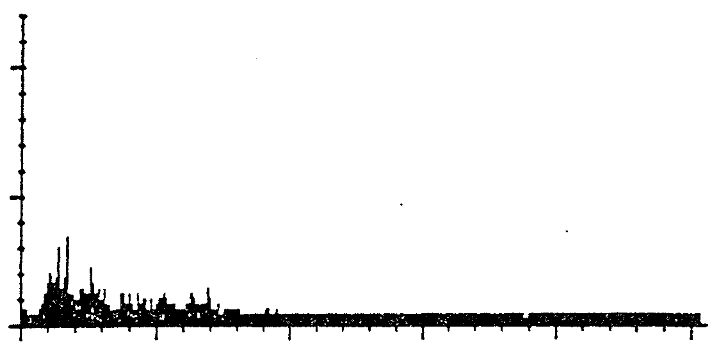
X FREQUENCY:
10 Hz/div



LONGITUDE

Y AMPLITUDE:
0.0001 in/sec/div

X FREQUENCY:
10 Hz/div



MICROPHONE

Y AMPLITUDE:
0.000002 psi/div

X FREQUENCY:
10 Hz/div

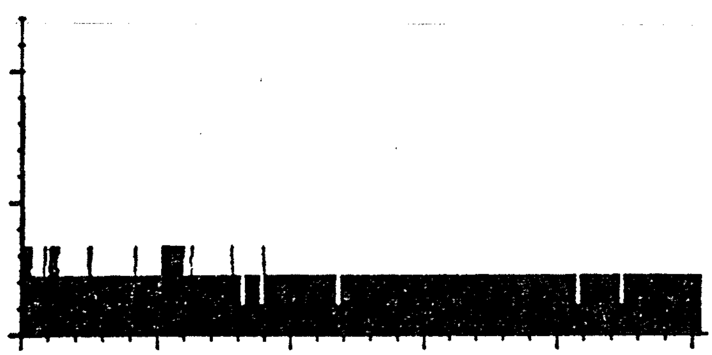


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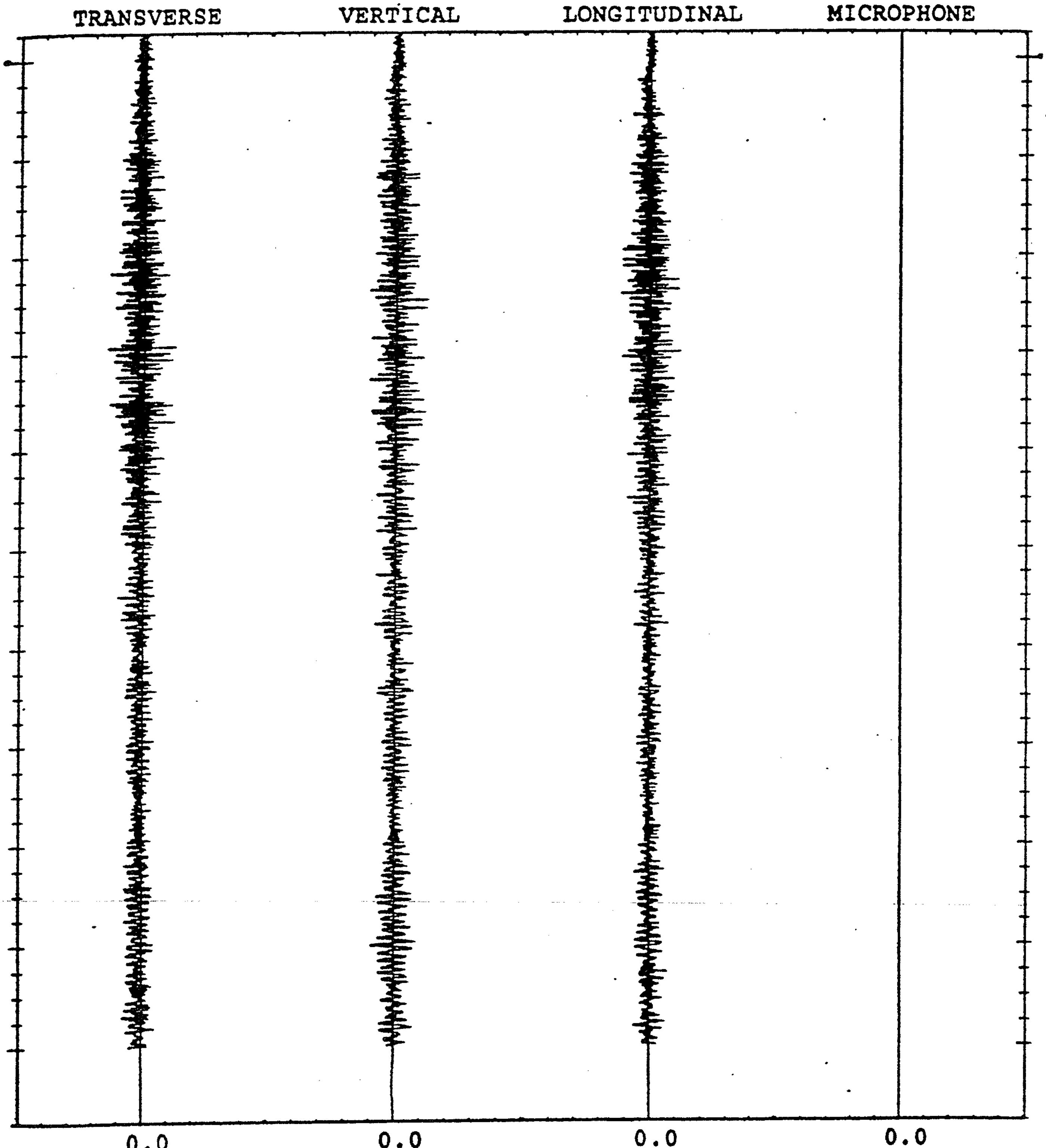
FIGURE 5-C
35 TO 40 MPH AMTRACK
T=0.014, V=0.012, L=0.012 IN/SEC.

CODE C80256A6.X1V **EVENT WAVEFORMS** PAGE # 1 of 1



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TIME SCALE: 250 msec/div 10.981 sec/page TRIGGER =

Vibra-Tech
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FIGURE 5-CC
35 TO 40 MPH AMTRACK
T=39 HZ, V=13 HZ, L=31 HZ

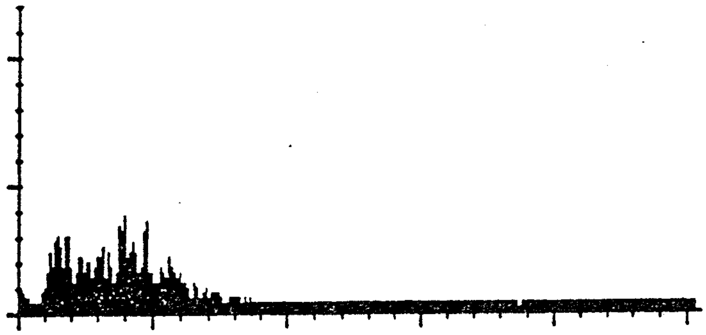
CODE C80256A6.X1V

FREQUENCY SPECTRUM

TRANSVERSE

Y AMPLITUDE:
0.0001 in/sec/div

X FREQUENCY:
10 Hz/div



VERTICAL

Y AMPLITUDE:
0.0001 in/sec/div

X FREQUENCY:
10 Hz/div

LONGITUDE

Y AMPLITUDE:
0.0001 in/sec/div

X FREQUENCY:
10 Hz/div

MICROPHONE

Y AMPLITUDE:
0.000002 psi/div

X FREQUENCY:
10 Hz/div

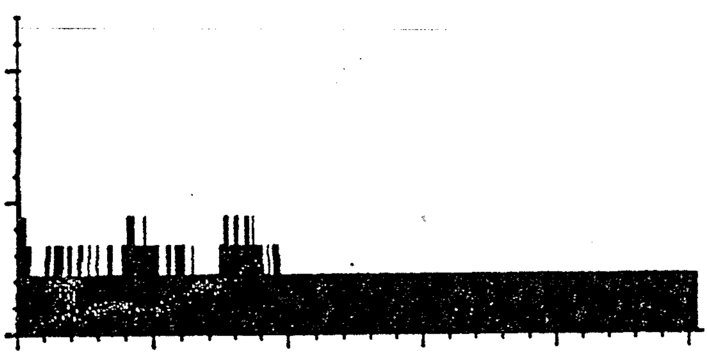


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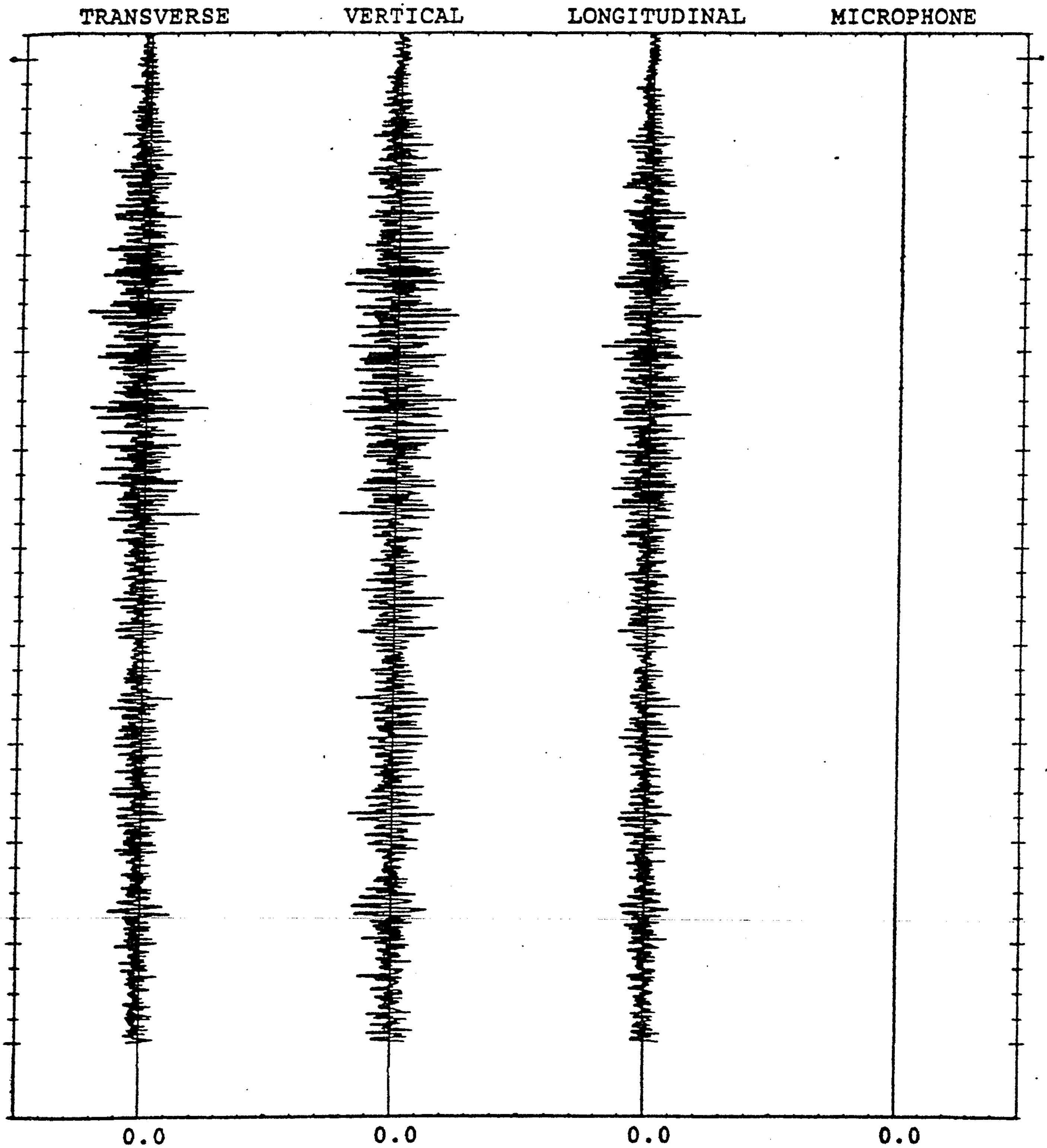
FIGURE 5-D
35 TO 40 MPH HEAVY FREIGHT
T=0.024, V=0.024, L=0.020 IN/SEC.

CODE C80256A3.DNV

EVENT WAVEFORMS

PAGE # 1 of 1



AMPLITUDE SCALE:GEO: 0.010 in/sec/div MIC: 0.0200 psi(L)/div
TIME SCALE: 250 msec/div 10.981 sec/page TRIGGER = •——

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FIGURE 5DD
35 TO 40 MPH HEAVY FREIGHT
T=11 HZ, V=12 HZ, L=14 HZ

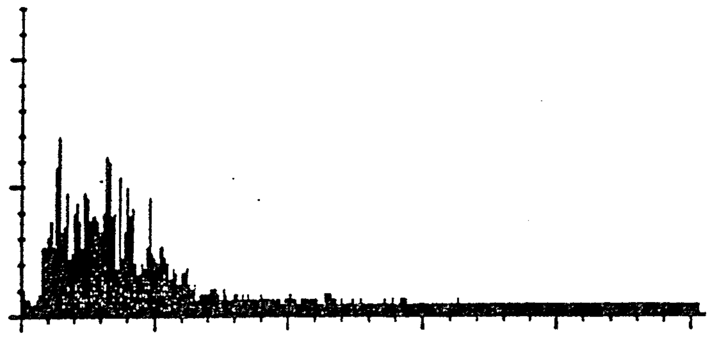
CODE C80256A3.DNV

FREQUENCY SPECTRUM

TRANSVERSE

Y AMPLITUDE:
0.0001 in/sec/div

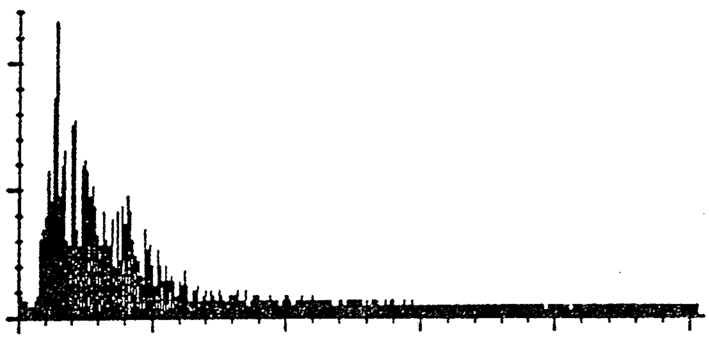
X FREQUENCY:
10 Hz/div



VERTICAL

Y AMPLITUDE:
0.0001 in/sec/div

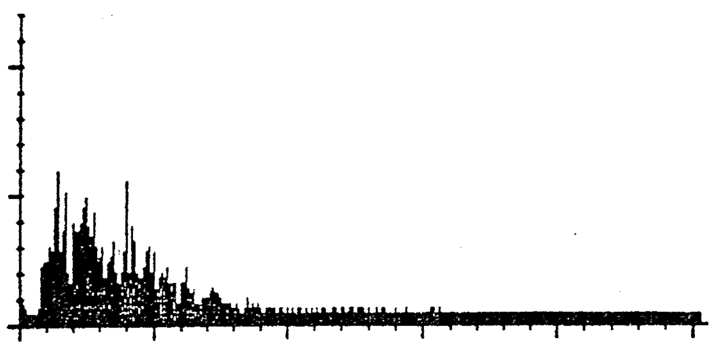
X FREQUENCY:
10 Hz/div



LONGITUDE

Y AMPLITUDE:
0.0001 in/sec/div

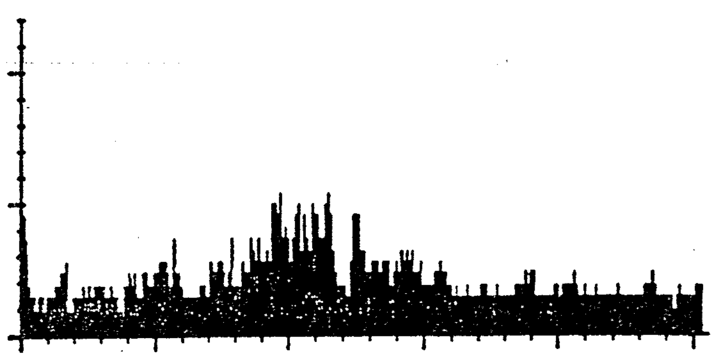
X FREQUENCY:
10 Hz/div



MICROPHONE

Y AMPLITUDE:
0.000005 psi/div

X FREQUENCY:
10 Hz/div



VIBRA-TECH
The Vibration Monitoring Experts
111 E. Kentucky Street, Louisville, KY 40203
502-587-7277 FAX 502-587-7280

January 16, 1995

Mr. Bill Johnson
Department of Transportation
State of Georgia
3993 Aviation Circle
Atlanta, Georgia 30336

Ref: Vibration Impact Study for Decatur Belt
Upgrade in Atlanta, Georgia

Dear Mr. Johnson,

Submitted herewith are five copies of our report for the above referenced project.

Services performed in this study included field vibration monitoring of ground vibration induced by train traffic, prediction of ground vibration in adjacent to the residential area along Decatur Belt Track, and computer modal analysis of a typical structure at the study area.

We appreciate the opportunity to be of service to you on this project. Please contact this office if you have any questions concerning this report.

Sincerely yours,
Vibra-Tech Engineers

M. Sharif

M. Sharif, P.E.
Structural Dynamic Analyst

vibra-tech

Report To:

Mr. Bill Johnson
Department of Transportation
State of Georgia
3993 Aviation Circle
Atlanta, Georgia 30336

Subject:

Vibration Impact Study For Decatur Belt In Atlanta, Georgia

By:

Vibra-Tech Engineers
Mohamad Sharif, P.E.
Dr. Thomas Fenski, P.E.
Brian Warner

Date:

January 16 1995

vibra-tech

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TABLE OF CONTENTS

1 -- EXECUTIVE SUMMARY

The Georgia Department of Transportation requested Vibra-Tech Engineers to perform an environmental noise and vibration study for the expansion of the Decatur Belt Track. The purpose of the study was to evaluate vibration and noise effects on structures and on human comfort induced by planed train traffic along the Decatur Belt Track. This report covers the vibration aspect of the study.

The preliminary investigation indicates that along the Decatur Belt Track, Ansley Park/Piedmont Heights area would be most effected by the rail traffic. The field vibration study along Southern Railroad was used as a source of excitation. The train activities along this road was a good representation of the train activities at the proposed site.

The waveform vibration induced by the train propagate through geology and transmitted into structural foundation. The geology would change the characteristic of the traveling waveform. The geology frequency response function of the site will control the characteristic of the waveform. This function was calculated by applying vibration energy into the soil at the study area, next to the track and recording the resulting vibration at the residential area. This function helps to calculate the effect of geology on vibration induced by the train.

The structural response to the ground vibration is predicted by using a computer modal analysis technique. The computed model was constructed based on the dynamic properties of a typical structure at the study area. The calculated ground vibration applied to the computer model. The induced developed stress at different structural component was calculated and compared to the damage criteria. The results indicates that the stresses are well below the structural strength.

The final scope of this project was related to the human response to the vibration. The predicted peak vibration level was compared with the recommended criteria established for human response complaints to vibration. The results indicates that vibration would be just perceptible to human. However, this level of vibration would not be troublesome to person.

It should be noted that the mathematical analysis used in this study considered the worst case scenario. The actual structures may experience less vibration. Also the ground vibration that was applied to the structure is calculated at 120 feet from the track. Other structures which are located more than 120 feet from the track will experience less vibration. The ground vibration is attenuating with distance.

2 -- INTRODUCTION

2•1 -- Objective:

The Georgia Department of Transportation is planning to upgrade the Decatur Belt Track. The upgraded railway would have higher train traffic, including Amtrak, heavy freight and commuter rail traffic.

A preliminary investigation by Vibra-Tech Engineer showed that the Ansley Park/Piedmont Heights area would be most effected by vibration generated by upgrading the Decatur Belt Rail.

The purpose of this study is to predict the ground vibration level at the residential area located at Ansley Park/Piedmont Heights, and also predict structural vibration levels and compare these values with the standard criteria for damage to structure and human comfort.

2•2 -- Scope Of Work:

1 - Locating a rail traffic area that represents the study area.

2 - Collection of ground vibration time history induced by different types of train traffic.

3 - Determination of geologic frequency response function at Ansley Park/Piedmont Height area.

4 - Calculation of ground vibration induced by train traffic, adjacent to residential structures.

5 - Computer modal analysis of typical structures at the study area.

6 - Calculation of the computer model vibration based on input ground vibration.

7 - Comparison of computer model response with standard vibration criteria for human comfort, and structural damage.

3 -- VIBRATION CRITERIA

3•1 -- Effect Of Vibration On Humans:

The criteria presented in Figure 1 for human response to vibration have been compared and agree with criteria proposed by other researchers. The graph shows several ranges of human perception to vibration which had been established experimentally by subjecting people to vertical vibrations as they stood on a shake table (1).

3•2 -- Structural Vibration Damage Criteria:

There are many studies undertaken by different agencies to establish damage criteria pertaining to residential and other sensitive structures. The German Standards evaluate the effect of steady-state vibration by measurement of vibration velocity. According to this criteria, for particle velocities below 2.5 mm/s (0.1 in/sec) damage is not possible for vibration levels 2.5 mm/s to 6 mm/s (0.24 in/sec) damage is very improbable for vibration levels below 6 mm/s to 10 mm/s (0.4 in/sec) damage is not probable. Stresses should be checked for vibration levels over 10 mm/s (0.4 in/sec) as damage is possible.

An American Society of Civil Engineers publication (2) recommends a criteria for old and sensitive structures. This criteria indicates that the vibration level should be less than 0.25 in/sec in a frequency range of 1 to 10 Hertz and 0.50 in/sec in frequency range of 40 Hertz or greater. For a frequency range between 10 to 40 Hertz, the level of vibration proportionally increases with frequencies from 0.25 in/sec to 0.5 in/sec.

The Association of Swiss Highway Engineers (3) distinguishes in their standard SN640312 four different categories of buildings, mainly according to the type of construction. Table 1 illustrates the structural type and maximum acceptable vibration criteria. The criteria is designed for machinery, traffic and construction work.

Fig 1 - Human Response to Vibration

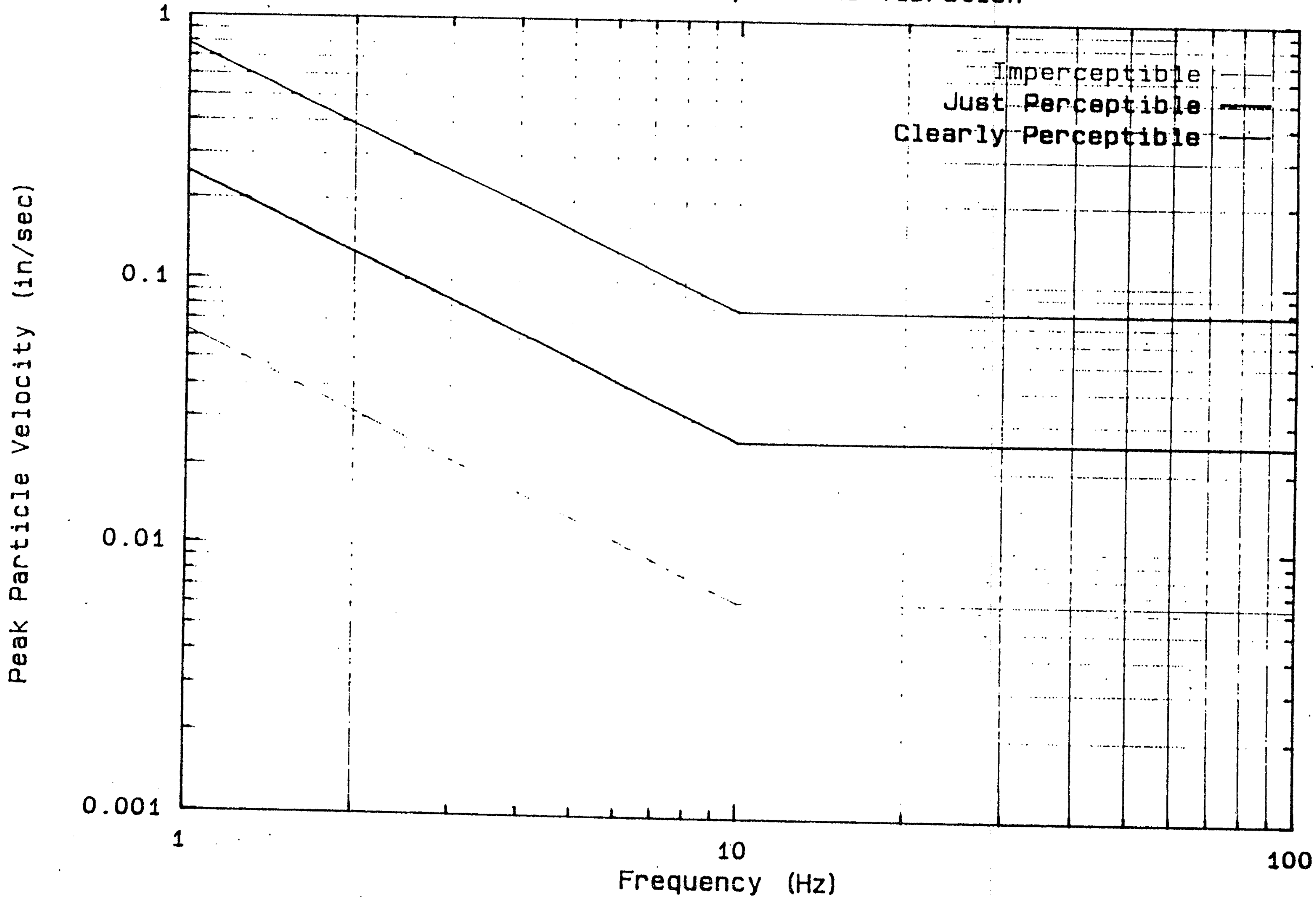


Table 1 -- Acceptance Criteria of SN 640312 for Different Types of Structures

Structure Type	Frequency	Max. Velocity (mm/s)*
reinforced - concrete and steel structures (without plaster) such as industrial buildings, bridges, retaining wall	10 - 30 30 - 60	12 12 - 18
Building with concrete floors and basement walls, above-grade walls of concrete, brick or ashlar masonry	10 - 30 30 - 60	8 8 - 12
Building with concrete basement floors and walls, above-grade masonry wall, timber joint floors	10 - 30 30 - 60	5 5 - 8
Buildings which are particularly vulnerable or worth protecting	10 - 30 30 - 60	3 3 - 5

* 1 in/s = 25 mm/s

4 -- INSTRUMENTATION

The following instrument was used in this sudy:

4•1 -- Multiseis V:

The system is a 4 channel light weight seismograph. Three channels are used for ground vibration velocity and the fourth channel is used to measure air over pressure. The following are specifications:

Seismic Range:	Up to 5 in/sec (127 mm/s) auto ranging
Trigger Levels:	0.01 to 5 in/sec (0.254 to 127 mm/s). (0.04 in/sec trigger level was selected in this study)
Frequency Sampling Rate:	1024 samples per channel per second, all channel, all recording types
Response:	Up to 250 Hertz, independent of record time

5 -- TEST PROCEDURE

The ground vibration was excited by the wheels of a moving train, each wheel acting as a moving force. Because of the irregularities and the random deflections of the rail, the induced vibration is considered to be random.

As the ground vibration travels through the geology, it is transmitted to the foundation of adjacent structures. The geology will alter the characteristic of the waveform as it travels from the rail track to the receiving point.

In order to predict ground vibration time history induced by the train adjacent to the structure the following study is required.

1) Measurement of ground vibration, adjacent to the track induced by similar type of train traffic. This waveform would be the input signal or source of vibration in the analysis.

2) Determination of geology frequency response function.

3) Calculation of the vibration time history at the receiving point or next to residential area (output signal) by applying the recorded train vibration waveform to the geology response function.

The analysis section of this report describes the technique in more detail.

The test measurements for the first step of the study were performed for the following, train traffic along Southern Rail Road.

* 40 MPH Commuter Train
* 40 MPH Heavy Freight Train
* 15 MPH Heavy Freight Train
* 35 MPH Commuter Train
* 40 MPH Amtrak
* 35 MPH Amtrak

A total of 10 seconds of vibration time history is collected per event.

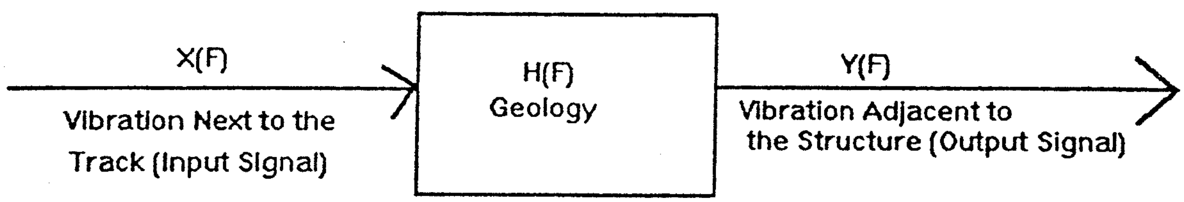
In order to calculate the geology frequency response function, a source of vibration should be induced into the geology and recorded as an input signal. The output signal would be recorded next to the residential area at the site. The input signal was applied into the geology by dropping a 50 pound weight from 25 feet and measuring the ground vibration within two feet of the drop site. The vibration that is created by the input energy is transmitted through the geology. The output signal is recorded approximately 120 feet away from the drop site.

The measurements were conducted using velocity recorders Multiseis V. The clock of the seismographs were synchronized and a trigger level of 0.05 in/sec was selected. The vibration induced by dropping the weight triggered both seismographs which recorded 1024 samples per second per channel of vibration time history. The ground vibration was recorded in three orthogonal directions. A three inch spike was used to secure the sensor with the ground to ensure coupling.

6 -- ANALYSIS

6•1 -- Geology Frequency Response:

Geology frequency response function is one of the dynamic properties of soil. This function describes how the magnitude of different frequency components of a waveform will be magnified or reduced as the wave travels through the system. It does not depend on the exciting vibration (input signal). The excitation can be a harmonic, random or transient function of time. Once this function is calculated with one type of the excitation, it can be used to predict the response of the system to any other type of excitation. The following sketch describes the concept.



$$H(F) = \frac{Y(F)}{X(F)} \qquad (1)$$

H(F) is the Geology Frequency Response Function
X(F) is the Fourier Transform of Input Signal x(t)
Y(F) is the Fourier Transform of Output Signal Y(t)

The calculation of geology frequency response function requires both an input and output signal. We needed to create a source of vibration adjacent to the track as an input signal, then measure the output signal next to the structure. To achieve this purpose, a 50 pound weight was dropped from 25 feet. The ground vibration within two feet of the dropped weight was recorded. This waveform is considered as input signal. The output signal was recorded next to the structure, 120 feet from the track. The following calculation defined geology frequency spectrum.

INPUT AUTO SPECTRUM:

(Data recorded within 2 feet of weight drop)

$$G_{AA} = \frac{1}{n}\sum (S_A * S_A) \qquad (2)$$

OUTPUT AUTO SPECTRUM:

(Data recorded within 120 feet from weight drop)

$$G_{BB} = \frac{1}{n}\sum (S_B * S_B) \qquad (3)$$

CROSS - SPECTRUM:

$$G_{AB} = \frac{1}{n}\sum (S_A * S_B) \qquad (4)$$

Where:

n = Averaging Number of Ensemble Size
S_A = Spectrum of Input Signal
S_B = Spectrum of Output Signal
$*$ = Complex Conjugate

$$H(F) = \frac{G_{AB}}{G_{AA}} = \frac{\text{CROSS-SPECTRUM}}{\text{INPUT AUTO SPECTRUM}} \qquad (5)$$

The proposed section of Decatur Belt track which passes through Ansley Park/Piedmont Height (study area) will be used for Amtrak and heavy freight traffic. In order to predict ground vibration at the structures in Ansley Park area, we needed a vibration signature induced by the same traffic flow that can be used as an input signal in equation (5). The present traffic along Southern Railroads line running between the Armour Rail Yard and the Brookwood Amtrak station, located at the intersection of Peach Tree Street and Dearing Road represent the same traffic flow as the proposed Decatur Belt at Ansley Park/Piedmont Height area. The ground vibrations induced by different train traffic along Southern Railroad were recorded. The sensors were placed within 10 feet of the tracks. The collected data was used as an input signal in equation (5). Finally, the output signal in equation (5) was used as ground vibration data, to calculate the structural vibration response in modal analysis.

6•2 -- Modal Analysis:

The objective of structural analysis is to predict the response of a given structure to certain prescribed loads or action. One can achieve this objective by physically testing a scale model or even a prototype of the structure, which is very expensive. The alternative for achieving this objective is Modal Analysis. Modal Analysis is a technique for simulation of structural response to certain load (train vibration) by using mathematical equations and knowledge of structural physical properties. Dynamic Modal Analysis is the process of determining the dynamic behavior of structures and is an effective method for investigating its vibration problems.

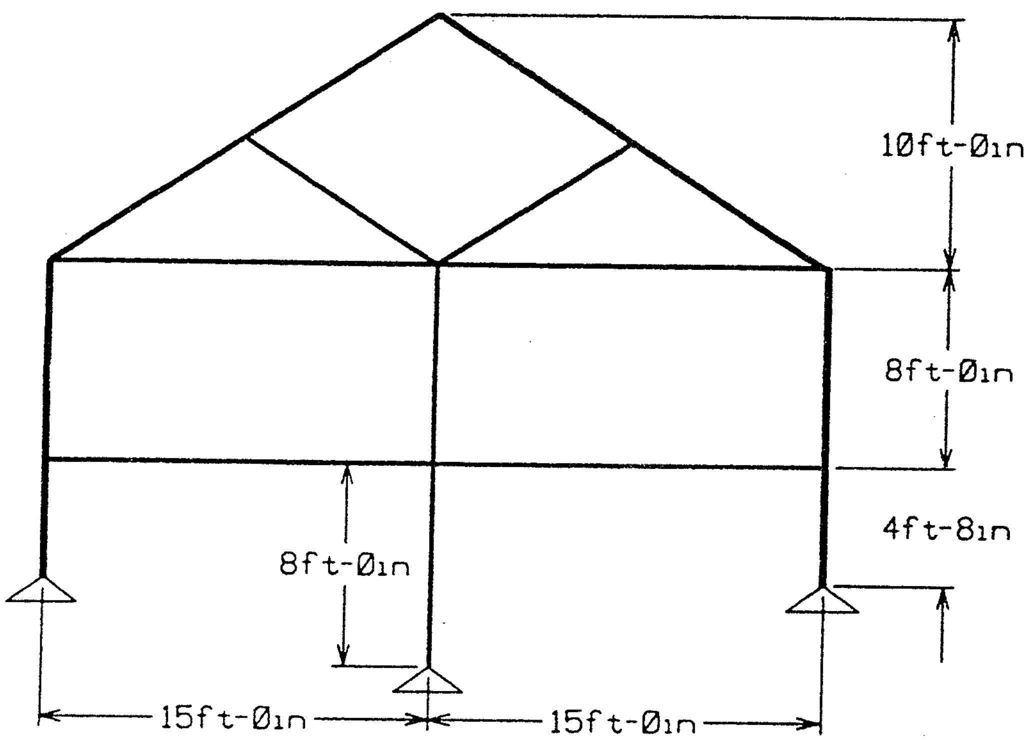


Figure 2 - Computer Model

The development of the analysis model was based upon a very conservative approach. From photographs and field notes of a house at 1758 Flagler Drive in Atlanta, Georgia, a generalized analysis model was developed which is intended to represent a typical house which could be expected to be found in this neighborhood.

The model developed for use in this analysis is a one-story wood framed structure with a full basement and a roof system with a 2:3 pitch. The width of the model is 30 feet with an 8 foot story height for both the main floor of the structure and the basement. The basement level is shown to be partially exposed in order to account for the effects of a "fall away" lot. Figure 2 illustrates the computer model. In the model, only the wood framing is assumed to be effective in resisting loads. The framing material is assumed to be southern pine with a 12 percent moisture content, a weight density of 35 psf, and a modulus of elasticity of 1600 ksi. The appropriate section properties have been developed from these assumptions.

Based upon this conservative house model, the analysis model consists of a plane frame configuration of 16 members and 12 joints. The frame is assumed to have three degrees of freedom at each joint which represent possible translation of the joint in the x and y directions and possible rotation of the joint about the z-axis. The direction of translation and rotation is shown in Appendix D of this report. The material properties given above are used to develop the stiffness and the mass matrices used in the analysis.

From field data, typical transverse, longitudinal, and vertical ground velocities, accelerations, and displacements were obtained. Using this information, a time history acceleration graph was developed, and the most extreme one second duration was identified. The data for this one second duration then was manipulated to create an even more severe dynamic excitation. The resulting "Design Transverse One Second Acceleration Graph" is given in the Appendix D. This enhanced data then was multiplied by three to generate a three second design time history acceleration graph which was used in the dynamic analysis.

Again, it is important to recognize that this is a very conservative approach to the analysis. No consideration was given to possible composite action of the framing system, and only the wood frame was considered as the load carrying system. In addition, the dynamic analysis was performed considering a "worst case" scenario of applied dynamic acceleration.

7 -- RESULTS

7•1 -- Prediction Of Ground Vibration:

One of the purposes of this project was the prediction of train induced ground vibration adjacent to the residential area. In order to achieve this purpose the area geology frequency response function should be calculated. The geology frequency response can be calculated by application of a sort of vibration energy at the source and recording the output vibration at the receiving point. The ratio of Cross Spectrum of the output and input signal to the input Auto Spectrum would resulted in geology frequency spectrum.

The ground vibration induced by similar train traffic flow was recorded next to the track along the Southern Rail Road. This data was used as the source of vibration. Appendix A of this report shows the actual ground vibration time history recorded next to the track. The recorded vibration was adjusted by geology frequency function. The final results show the ground vibration next to the residential structure. Appendix B illustrates the calculated vibration time history next to the residential area. Appendix C compares the frequency spectrum of the input signal (vibration next to the track) with the output signal (vibration next to the residential area). The graph shows the geology dissipates the high frequency, while in some events it amplifies the low frequency. Table 2 shows the peak ground recorded vibration at the track and peak calculated ground vibration adjacent to the residential area.

7•2 -- Dynamic Analysis:

Based upon the modal analysis calculation, the first four natural frequencies are 2.6 Hz, 5.4 Hz, 9.9 Hz, and 31.9 Hz. The maximum movement perceptible to humans will be present at the main floor level. This corresponds to the velocity influence at joints 2, 6, and 11. The displacement and peak velocity at each joint per direction is shown in Appendix D of this report. The maximum velocity is 0.0395 inch per second. This velocity result will be just on the threshold of human perception.

Table 2 -- Peak Ground Vibration Velocity

Vibration Source Transverse	Input x(t) in/sec	Output y(t) in/sec	Gain
35 MPH Freight Train	0.065	0.005	0.077
35 MPH Amtrak	0.059	0.004	0.068
40 MPH Amtrak	0.074	0.004	0.054
15 MPH Decatur Belt Freight Train	0.039	0.003	0.077
35 MPH Commuter Train	0.026	0.002	0.077
10 MPH Decatur Belt Train	0.113	0.011	0.097

Vibration Source Vertical	Input x(t) in/sec	Output y(t)in/sec	Gain
35 MPH Freight Train	0.083	0.036	0.434
35 MPH Amtrak	0.068	0.053	0.779
40 MPH Amtrak	0.112	0.034	0.304
15 MPH Decatur Belt Freight Train	0.053	0.025	0.472
35 MPH Commuter Train	0.044	0.035	0.795
10 MPH Decatur Belt Train	0.093	0.054	0.581

Vibration Source Longitudinal	Input x(t) in/sec	Output y(t) in/sec	Gain
35 MPH Freight Train	0.178	0.030	0.169
35 MPH Amtrak	0.128	0.028	0.219
40 MPH Amtrak	0.156	0.025	0.160
15 MPH Decatur Belt Freight Train	0.041	0.010	0.244
35 MPH Commuter Train	0.032	0.008	0.250
10 MPH Decatur Belt Train	0.118	0.031	0.263

8 -- CONCLUSION

The tests and analysis performed created a general mathematical model used to predict the propagation of heavy railway induced vibration on to the Ansley Park/Piedmont Heights area. This area was chosen based on it's close proximity to the proposed rail-way expansion as compared to other neighborhoods adjacent to the expansion. Geological and structural computer models were created from test and measurement data obtained on the existing and planned areas. The effects of the rail-way traffic were investigated for both structural degradation and for amount of human perceptibility.

8•1 -- Structure Degradation:

According to the computer models, the applied load on the building attributable to the rail traffic will be minimal compared to other activities in the structure. Comparison of calculated vibration levels and their frequency components to the structural vibration damage criteria located in Table 1 reveals that vibration levels at all frequencies are below the acceptable limits. And no structural degradation will be caused by the rail-way traffic.

8•2 -- Human Perceptibility:

The predicted peak particle velocity and frequency levels of vibration at the study area is compared with human response to vibration. The results show the peak vibration level is above the vibration level barley perceptible to human. (see Figure 1) However, the value is below vibration level which is clearly perceptible to human and should not be troublesome to persons. It is important to recall that the computer modal analysis which is used in this study was very conservative and considering a "worst case" scenario.

9 -- REFERENCES

1) Ministry of Metallurgy and Chem. Eng., Instruction I 200-54 "Planning and Calculation of Building Structures for Dynamic Loading from Machinery" (in Russian), Moscow (USSR), 1955.

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3) Institution of Swiss Highway Engs. (VSS), Swiss standard SN 640312: "Vibration Effect on Structures" (in German), VSS secretarial Zurich, November, 1978.